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IDENTIFICATION, ASSESSMENT, AND CONTROL OF FUGITIVE PARTICULATE EMISSIONS

by

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Assessments		Stationary Sources	14B
Particles		Fugitive Emissions	14G
Dust		Particulate	11G
Aerosols			07D
Processing			14H

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ABSTRACT

To assist control agency personnel and industry personnel in evaluating fugitive emission control plans and in developing cost-effective control strategies, the U.S. Environmental Protection Agency has funded the preparation of a technical manual on the identification, assessment, and control of fugitive particulate emissions. This manual's organizational structure follows the steps to be undertaken in developing a cost-effective control strategy for fugitive particulate emissions. The procedural steps are the same whether the sources of interest are contained within a specific industrial facility or distributed over an air quality control jurisdiction.

The manual summarizes the quality and extent of published performance data for control systems applicable to open dust sources and process sources. The scheme developed to rate performance data reflects the extent to which a control efficiency value is based on mass emission measurement and reported in enough detail for adequate validation. In addition to presenting a cost analysis methodology, the manual identifies primary cost elements and sources of cost data and presents a fully worked industrial example of cost-effective control strategy development.

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SECTION 1
INTRODUCTION

Fugitive particulate emissions are emitted by a wide variety of sources both in the industrial and in the nonindustrial sectors. Fugitive emissions refer to those air pollutants that enter the atmosphere without first passing through a stack or duct designed to direct or control their flow.

Fugitive particulate emission sources may be separated into two broad categories: process sources and open dust sources. Process sources of fugitive emissions are those associated with industrial operations that alter the chemical or physical characteristics of a feed material. Examples are emissions from charging and tapping of metallurgical furnaces and emissions from crushing of mineral aggregate. Such emissions normally occur within buildings and, unless captured, are discharged to the atmosphere through forced or natural draft ventilation systems. Open dust sources entail the entrainment of solid particles into the atmosphere by the forces of wind or machinery acting on exposed materials. Open dust sources include industrial sources associated with the open transport, storage, and transfer of raw, intermediate, and waste materials, and nonindustrial sources such as unpaved and paved public roads and construction activities.

1.1 PURPOSE OF DOCUMENT

To assist control agency personnel in evaluating fugitive emissions control plans and to assist industry personnel in the development of cost-effective control strategies, the U.S. Environmental Protection Agency has funded the preparation of this technical guidance document on the identification, assessment, and control of fugitive particulate emissions. The document describes the procedures for developing a cost-effective strategy for the control of fugitive particulate emissions within any specific plant or area setting. Also, it provides sources of data or in some cases actual data needed to implement the procedures.

Within this document, cost-effectiveness is defined as the annualized cost of control divided by the reduction in total annual particulate emissions ($/Mg), as a result of the fugitive emissions control system being employed. Control costs include the capital, operating, and maintenance costs associated with the system over its useful life.

The particle size fractions cited in this manual include:

TP	Total airborne particulate matter.
TSP	Total suspended particulate matter, as represented approximately by particles equal to or smaller than 30 μm in aerodynamic diameter.
IP	Inhalable particulate matter consisting of particles equal to or smaller than 15 μm in aerodynamic diameter.
PM_{10}	Particulate matter consisting of particles equal to or smaller than 10 μm in aerodynamic diameter.
RP	Respirable particulate matter consisting of particles equal to or smaller than approximately 3.5 μm in aerodynamic diameter
FP	Fine particulate matter consisting of particles equal to or smaller than 2.5 μm in aerodynamic diameter.

Respirable particulate matter refers to the particle size fraction penetrating the Dorr-Oliver cyclone used as a standard device for industrial hygiene measurements. The cyclone has a 50% cut-point of about 3.5 μmA when operated at 2 L/min and is the device chosen in the United States to most closely simulate the penetration of dust into the lung.

Unless otherwise indicated, use of the term particulate emissions in this document refers to the particle size fraction collected by the standard high-volume sampler, which is the reference device for the existing National Ambient Air Quality Standards for particulate matter. Although the standard high-volume sampler does not have a sharp particle size cut-point for capture of airborne particulate matter, an effective cut-point of 30 μm aerodynamic diameter (μmA) is frequently assigned. This particle size fraction is normally referred to as total suspended particulate matter (TSP).

1.2 SCOPE OF DOCUMENT

This document describes the recommended steps in developing a cost-effective control strategy for specific sources of fugitive particulate emissions.

Whether the sources of interest are contained within a specific industrial facility or distributed over an air quality control jurisdiction, the general procedure for control strategy development is the same. The steps are as follows:

Step 1: Source identification.

Step 2: Preparation of an emissions inventory.

Step 3: Identification of control alternatives.

Step 4: Estimation of control system performance.

Step 5: Estimation of control costs.

Step 6: Selection of cost-effective controls.

Figure 1-1 graphically summarizes the procedure.

It is assumed that the need for reduction in emissions has been determined as required to achieve a desired net improvement in air quality or to provide an offset for an increase in emissions from an expanding source operation. The techniques for establishing relationships between air quality and source emissions are described in Appendix A.

The organization of this document (i.e., chapter designations) reflects an emphasis on control technology in relation to the other technical areas associated with control strategy development. Also greater emphasis is placed on open dust sources rather than process sources. This, in fact, is consistent with the larger body of available data on the performance of open dust source controls (focusing on controls applicable to unpaved roads). Finally, although fugitive particulate emissions can be reduced by reducing the extent of the source, this document focuses on the use of "add-on" controls which do not affect the size or throughput of the source.

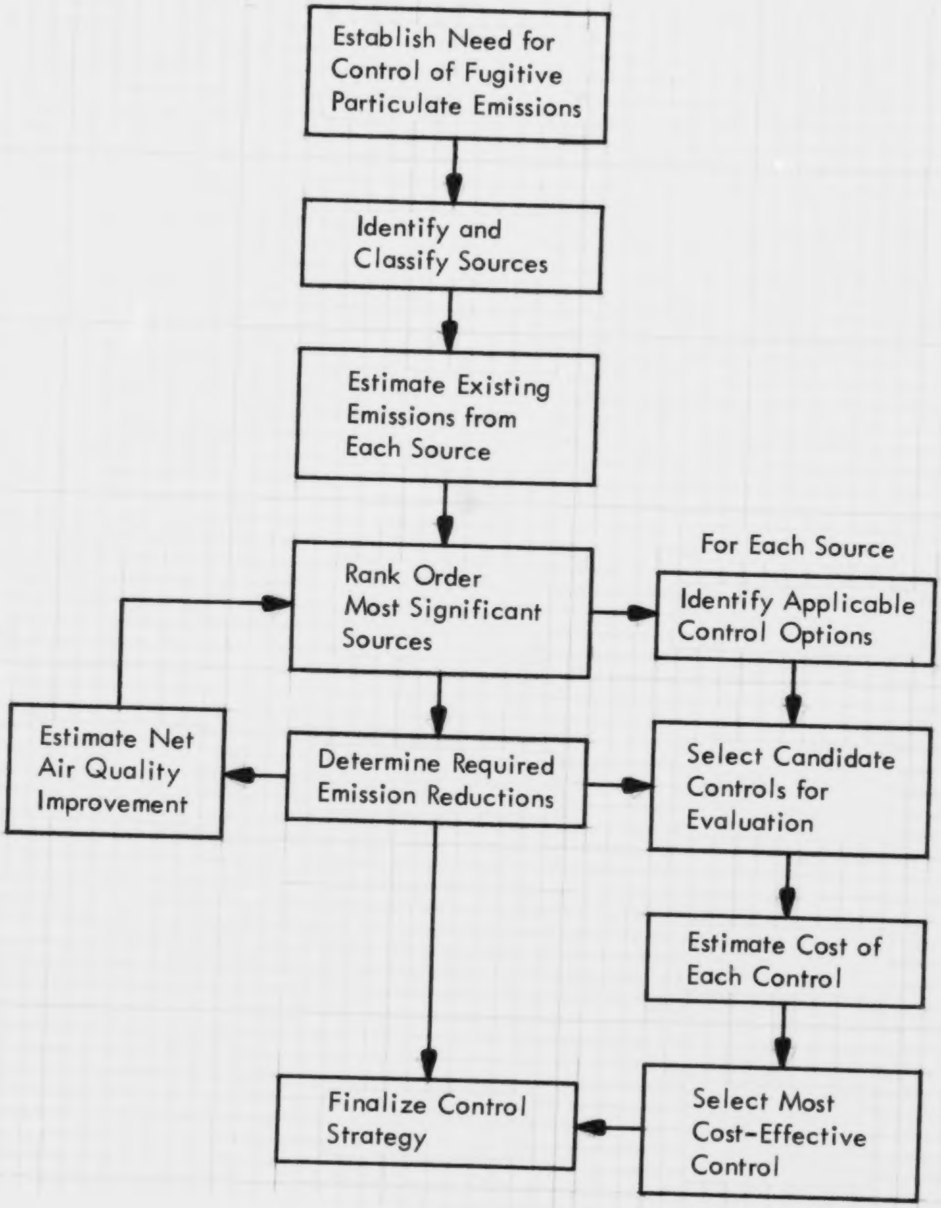
Establish Need for Control of Fugitive Particulate Emissions
Identify and Classify Sources
Estimate Existing Emissions from Each Source
Rank Order Most Significant Sources
For Each Source
Identify Applicable Control Options
Estimate Net Air Quality Improvement
Determine Required Emission Reductions
Select Candidate Controls for Evaluation
Estimate Cost of Each Control
Finalize Control Strategy
Select Most Cost-Effective Control

Figure 1-1. Flow diagram for the identification, assessment, and control of fugitive particulate emissions

While a variety of control techniques applicable to sources of fugitive particulate emissions are discussed in this document, control efficiency values are specified only for those control options which have been tested for effectiveness. However, the reader is referred to other review documents which present estimated values of control efficiency for control options which have no published performance data.

The chapter contents of this document are summarized as follows:

- **Chapter 2 (Identification of Sources)** defines the terms used to identify sources of fugitive particulate emissions, describes generic source categories, and classifies specific sources by generic category within each major industry in a matrix format.
- **Chapter 3 (Preparation of an Emissions Inventory)** presents a review of the standard procedures used to develop an emissions inventory and to determine the desired reduction in particulate emissions from fugitive sources.
- **Chapter 4 (Identification of Control Alternatives)** identifies control alternatives by generic category and presents a matrix of feasible control alternatives for specific sources within each major industry.
- **Chapter 5 (Estimation of Control System Performance--Open Sources)** documents and rates published performance data on open source controls, identifies the parameters which affect control performance, and compiles performance data for control alternatives applicable to each generic source category.
- **Chapter 6 (Estimation of Control System Performance--Process Sources)** documents and rates published performance data on process source controls, identifies the parameters which affect control performance, and compiles performance data for control alternatives applicable to each generic source category.
- **Chapter 7 (Estimation of Control Costs and Cost-Effectiveness)** describes estimation procedures for capital, operating, and maintenance costs, and outlines the methodology for calculating cost-effectiveness of continuously and periodically applied controls.
- **Chapter 8 (Hypothetical Case Study)** presents a fully worked industrial example illustrating the procedural steps for control strategy development, including the capital, operation, and maintenance costs of representative controls.

- **Appendix A (Estimation of Air Quality Impact/Improvement)** describes the mathematical modeling techniques for assessing the air quality impact of specific sources and for predicting the improvement in air quality resulting from the implementation of specific controls.
- **Appendix B** is a glossary of terms used in this manual.

Other than complying with air pollution regulations, the control of fugitive particulate emissions provides a number of tangible benefits. The reduction of ground-level particulate concentrations within an industrial complex prolongs the life of mechanical equipment and reduces the adversity of the worker environment, thereby increasing production efficiency and product quality. Finally, the industry that controls fugitive particulate emissions that are otherwise visible to the public is perceived positively by the surrounding community.

SECTION 2
SOURCE IDENTIFICATION

The first step in the control strategy development procedure is the identification of sources to be considered as candidates for control. This section defines the basic terminology and lists the common types of fugitive particulate emission sources. A glossary of terms further defining the various types of fugitive sources and their associated controls is provided in Appendix B.

2.1 DEFINITIONS AND EXAMPLES

Fugitive emissions refer to those air pollutants that (a) enter the atmosphere without first passing through a stack or duct designed to direct or control their flow, or (b) leak from ducting systems. Sources of fugitive particulate emissions may be separated into two broad categories: process sources and open dust sources.

Process sources of fugitive emissions are those associated with industrial operations that alter the chemical or physical characteristics of a feed material. Examples are emissions from charging and tapping of metallurgical furnaces and emissions from crushing of mineral aggregates. Such emissions normally occur within buildings and, unless captured, are discharged to the atmosphere through forced or natural draft ventilation systems. However, a process source of fugitive emissions can occur in the open atmosphere (e.g., scrap metal cutting). The most significant industrial process sources of fugitive particulate emissions are listed by industry in Table 2-1.

Open dust sources are those that entail generation of fugitive emissions of solid particles by the forces of wind or machinery acting on exposed materials.

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TABLE 2-1. CATEGORIES OF PROCESS FUGITIVE SOURCES

Industry	Process source
Iron and Steel Plants	Coal Crushing/Screening
	Coke Ovens
	Coke Oven Pushing
	Sinter Machine Windbox
	Sinter Machine Discharge
	Sinter Cooler
	Blast Furnace Charging
	Blast Furnace Tapping
	Slag Crushing/Screening
	Molten Iron Transfer
	BOF Charging/Tapping/Leaks
	Open Hearth Charging/Tapping/Leaks
	EAF Charging/Tapping/Leaks
	Ingot Pouring
	Continuous Casting
	Scarfing
Ferrous Foundries	Furnace Charging/Tapping
	Ductile Iron Inoculation (w/wo tundish cover)
	Pouring of Molten Metal
	Casting Shakeout
	Cooling/Cleaning/Finishing of Castings
	Core Sand and Binder Mixing
Primary Aluminum Production	Grinding/Screening/Mixing/ Paste Production
	Anode Baking
	Electrolytic Reduction Cell
	Refining and Casting
Primary Copper Smelters	Roaster Charging
	Roaster Leaks
	Furnace Charging/Tapping/ Leaks
Primary Copper Smelters	Slag Tapping/Handling
	Converter Charging/Leaks
	Blister Copper Tapping/Transfer
	Copper Tapping/Casting

TABLE 2-1. (continued)

Industry	Process source
Primary Lead Smelters	Raw Material Mixing/Pelletizing Sinter Machine Leaks Sinter Return Handling Sinter Machine Discharge/Screens Sinter Crushing Blast Furnace Charging/Tapping Lead and Slag Pouring Slag Cooling Slag Granulator Zinc Fuming Furnace Vents Dross Kettle Silver Retort Building Lead Casting
Primary Zinc Production	Sinter Machine Windbox Discharge Sinter Machine Discharge/Screens Coke-Sinter Mixer Furnace Tapping Zinc Casting
Secondary Aluminum Smelters	Sweating Furnace Smelting Furnace Charging/Tapping Fluxing Dross Handling and Cooling
Secondary Lead Smelters	Scrap Burning Sweating Furnace Charging/Tapping Reverb Furnace Charging/Tapping Blast Furnace Charging/Tapping Pot Furnace Charging/Tapping Tapping of Holding Pot Casting
Secondary Zinc Production	Sweating Furnace Charging/Tapping Hot Metal Transfer Melting Furnace Charging/Tapping Distillation Retort Charging/Tapping Distillation Furnace Charging/Tapping Casting

TABLE 2-1. (concluded)

Industry	Process source
Secondary Copper, Brass/ Bronze Production	Sweating Furnace Charging/Tapping Dryer Charging/Tapping Melting Furnace Charging Casting
Ferroalloy Production	Raw Materials Crushing/ Screening Furnace Charging Furnace Tapping Casting
Cement Manufacturing	Limestone/Gypsum Crushing and Screening Coal Grinding
Lime Manufacturing	Limestone Crushing/Screening Lime Screening/Conveying
Rock Products	Blasting Primary Crushing/Screening Secondary Crushing/Screening Tertiary Crushing Screening
Asphalt Concrete Plants	Aggregate Crushing/Screening Pugmill
Coal-Fired Power Plants	Coal Pulverizing/Screening
Grain Storage and Processing	Grain Cleaning Grain Drying
Wood Products Industry	Log Debarking/Sawing Veneer Drying Plywood Cutting Plywood Sanding
Mining	Blasting Crushing/Screening

Open dust sources include industrial sources of particulate emissions associated with the open transport, storage, and transfer of raw, intermediate, and waste aggregate materials and nonindustrial sources such as unpaved roads and parking lots, paved streets and highways, heavy construction activities, and agricultural tilling. Generic categories of open dust sources are listed in Table 2-2.

TABLE 2-2. GENERIC CATEGORIES OF OPEN DUST SOURCES

1. Unpaved Travel Surfaces
   - Roads
   - Parking lots and staging areas
   - Storage piles
2. Paved Travel Surfaces
   - Streets and highways
   - Parking lots and staging areas
3. Exposed Areas (wind erosion)
   - Storage piles
   - Bare ground areas
4. Materials Handling
   - Batch drop (dumping)
   - Continuous drop (conveyor transfer, stacking)
   - Pushing (dozing, grading, scraping)
   - Tilling

The partially enclosed storage and transfer of materials to or from a process operation do not fit well into either of the two categories of fugitive particulate emissions defined above. Examples are partially enclosed conveyor transfer stations and front-end loaders operating within buildings. Nonetheless, partially enclosed materials handling operations will be classified as open sources.

2.2 SOURCE CHARACTERISTICS

Unlike ducted sources of particulate emissions, which typically can be characterized as continuously emitting, fugitive emission rates have a high degree of temporal variability. Industrial process sources of fugitive particulate emissions are usually associated with batch operations, and emissions fluctuate widely during the process cycle. Open dust sources within industry also exhibit large fluctuations because of the sporadic nature of materials handling operations and the effects of precipitation and wind on the emissions potential.

In addition, fugitive emissions are characteristically diffuse in nature and are discharged from a wide variety of source configurations. For example, vehicles which entrain surface dust from industrial roads are best represented as individual moving point sources (or as a line source for high traffic density), while process fugitive emissions discharged from building vents are usually depicted as area sources or virtual point sources.

The various types of open dust sources listed in Table 2-2 can be found either in an industrial facility or in the public sector. The mechanisms of dust formation and thus the type of controls which can be applied in either case are essentially the same. However, both the suitability and cost-effectiveness associated with a specific control measure can change significantly when applied in an industrial setting as compared to the same control used for public sector sources. Therefore, the control strategies used by public agencies often differ from those employed by industrial concerns.

A number of public sector sources are perceived as single sources when in actuality they are a series of different dust generating operations confined to the same locality. Examples of this type of source include construction and demolition activities, both of which involve dust generation by various materials handling operations as well as vehicular traffic. Table 2-3 lists the specific sources associated with construction and demolition activities using the same general notation indicated in Tables 2-1 and 2-2 above.

TABLE 2-3. OPEN DUST SOURCES ASSOCIATED WITH CONSTRUCTION AND DEMOLITION

1. Construction Sites
   - Vehicular traffic on unpaved surfaces
   - Storage piles
   - Mud/dirt carryout onto paved travel surfaces
   - Exposed areas
   - Batch drop operations
   - Pushing (earth moving)
2. Demolition Sites
   - Vehicular traffic on unpaved surfaces
   - Storage piles
   - Mud/dirt carryout onto paved travel surfaces
   - Exposed areas
   - Batch drop operations
   - Pushing (dozer operation)
   - Blasting

One final public sector source worthy of note is agricultural tilling. Tilling involves those operations associated with soil preparation, soil maintenance, and crop harvesting activities. The emissions from these operations are generally significant but are usually not controlled except by operational modifications. Since add-on controls are not generally applicable to agricultural tilling, such will not be covered in detail in this document.

2.3 EXAMPLE INDUSTRIAL FACILITY

To illustrate the various types and classifications of sources found in industrial facilities, Figure 2-1 shows a simplified process flow diagram for a typical rock crushing plant. This particular example was selected since it entails both process and open dust sources and has a well defined process flow. Each source of fugitive particulate emissions in the facility has been identified on the diagram and numbered in consecutive order. The

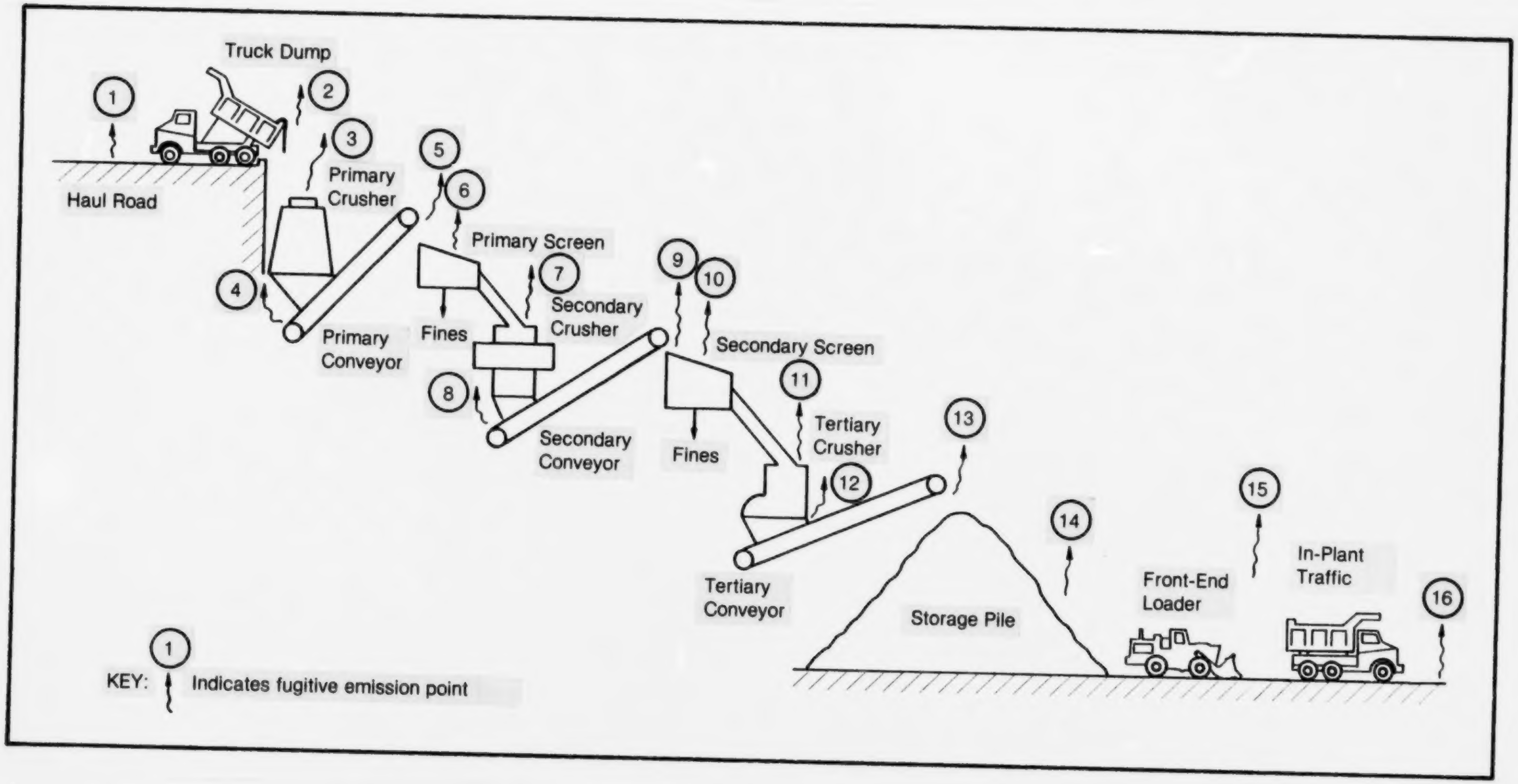
Truck Dump
①
②
③
Haul Road
Primary Crusher
⑤
⑥
④
Primary Conveyor
Primary Screen
⑦
Fines
Secondary Crusher
⑧
Secondary Conveyor
⑨
⑩
Secondary Screen
⑪
Fines
Tertiary Crusher
⑫
⑬
Tertiary Conveyor
Storage Pile
⑭
⑮
Front-End Loader
In-Plant Traffic
⑯
KEY: ① Indicates fugitive emission point

Figure 2-1. Simplified process flow diagram for a typical rock crushing plant

classification of each source using the definitions presented above is shown in Table 2-4. This illustration should assist the environmental professional in understanding the nomenclature used in subsequent sections of this document. Diagrams for other processes can be found in the literature.[2-5]

TABLE 2-4. SOURCE IDENTIFICATION FOR A TYPICAL ROCK CRUSHING PLANT[a]

Source ID No.[b]	Description of dust producing operation	Source classification
1	Truck traffic on haul road	Open dust
2	Truck dump	Open dust
3	Primary crushing	Process
4	Material transfer to conveyor	Open dust
5	Material transfer to screen	Open dust
6	Primary screening	Process
7	Secondary crushing	Process
8	Material transfer to conveyor	Open dust
9	Material transfer to screen	Open dust
10	Secondary screening	Process
11	Tertiary crushing	Process
12	Material transfer to conveyor	Open dust
13	Material transfer to storage pile	Open dust
14	Storage pile wind erosion	Open dust
15	Loadout to trucks	Open dust
16	Truck traffic leaving plant	Open dust

[a] See Figure 2-1 for process flow.

[b] From Figure 2-1.

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SECTION 3
PREPARATION FOR AN EMISSIONS INVENTORY

Once the fugitive particulate emission sources within an industrial facility or an air quality control region are identified, the next step is to prepare a detailed emissions inventory. This will provide critical information as to the types and locations of sources which account for most of the existing fugitive particulate emissions. The subsections below describe the techniques commonly used for emission inventory development.

In developing an emissions inventory for a complex industrial facility or an air quality control region, the large number of individual sources and the diversity of source types make impractical the field measurement of emissions at each point of release. In most cases the only feasible method of determining source-by-source emissions is to estimate the typical emission rate for each of the source type and to adjust each estimate for the size or activity of the source and the level of control.

Calculation of the estimated emission rate for a given source requires data on source extent, uncontrolled emission factor, and control efficiency. The mathematical expression for this calculation is as follows:

$$R = Me\,(1 - c) \tag{3-1}$$

where:

R = estimated mass emission rate

M = source extent

e = uncontrolled emission factor, i.e., mass of uncontrolled emissions per unit of source extent

c = fractional efficiency of control

The source extent is the appropriate measure of source size or level of activity which is used to scale the uncontrolled emission factor to the particular source in question. For process sources of fugitive particulate emissions, the source extent is the production rate, i.e., the mass of product per unit time. Similarly, the source extent of an open dust source entailing a batch or continuous drop operation is the rate of mass throughput.

For other categories of open dust sources, the source extent is related to the area of the exposed surface which is disturbed by either wind or mechanical forces. In the case of wind erosion, the source extent is the area of erodible surface. For emissions generated by mechanical disturbance, source extent is also the area (or volume) of the material from which the emissions emanate. For vehicle travel, the disturbed surface area is the travel length times average daily traffic (ADT) count, with each vehicle having a disturbance width equal to the width of a travel lane.

Normally, the "uncontrolled" emission factor incorporates the effects of natural mitigation (e.g., rainfall). If anthropogenic control measures (e.g., treating the surface with a chemical binder which forms an artificial crust) are applied to the source, the uncontrolled emission factor must be reduced to reflect the resulting fractional control.

3.1 PUBLISHED EMISSION FACTORS FOR ESTIMATING EMISSIONS

The document "Compilation of Air Pollutant Emission Factors" (AP-42), published by the U.S. Environmental Protection Agency (EPA) since 1972, is a compilation of emission factor reports for the most significant emission source categories. Supplements to AP-42 have been published for both new emission source categories and for updating existing emission source categories, as more information about sources and control of emissions has become available.

Data obtained from source tests, material balance studies, and engineering estimates are used to calculate the emission factors in AP-42. These data are obtained from a variety of sources, including published technical papers and reports, documented emission testing results, and personal communications. Some data sources provide complete details about their collecting and analyzing procedures, whereas other provide only sketchy information in this regard.

Emission factors for sources of primary particulate emissions have been compiled in AP-42. However, because the national effort to control industrial sources of pollution has focused on emissions from ducted sources, only a small portion of these factors apply to either process fugitive particulate emissions or open dust sources. In addition, because of the difficulty in quantifying the full particle size spectrum of particulate emissions from fugitive sources, emission factors for these sources frequently are poorly defined with regard to particle size.

3.1.1 Types of Emission Factors

The most reliable emission factors are based on field tests of representative sources using a sound test methodology reported in enough detail for adequate validation. Usually the emission factor for a given source operation, as presented in a test report, is derived simply as the arithmetic average of the individual emission factors calculated from each test of that source. Frequently the range of individual emission factor values is also presented.

As an alternative to the presentation of an emission factor as a single-valued arithmetic mean, an emission factor may be presented in the form of a predictive equation derived by regression analysis of test data. The predictive emission factor equation mathematically relates emissions to parameters which characterize source conditions. An emission factor equation is useful if it is successful in "explaining" much of the observed variance in emission factor values on the basis of corresponding variances in specific source parameters. This enables more reliable estimates of source emissions on a site-specific basis by allowing for correction of the emission factor to specific source conditions.

In practice, the development of emission factor equations has been limited to open dust source operations, each defined on the basis of a single dust generation mechanism which crosses industry lines. An example would be vehicular traffic on unpaved roads. To establish its applicability, each generic equation has been developed from test data obtained in different industries. The correction parameters appearing in the predictive emission factor equations for open dust sources fall into three categories:

1. Measures of sources activity or energy expended (for example, the speed and weight of a vehicle traveling on an unpaved road).
2. Properties of the material being disturbed (for example, the content of suspendable fines in the surface material on an unpaved road).
3. Climatic parameters (for example, number of precipitation-free days per year on which emissions tend to be at a maximum).

3.1.2 Quality Rating Scheme

In selecting candidate emission factors for inclusion in AP-42, the principal consideration centers around the reliability of each factor being considered in relation to the reliability factors currently reported in AP-42 for the same source. The emission factor rating system for AP-42 emission factors, was developed by the U.S. EPA, Office of Air Quality Planning and Standards (April 1980). This scheme entails the rating of test data quality followed by the rating of the adequacy of the test data relative to the characterization of the uncontrolled emissions from the source in question.

The rating system for a particular emission factor test data set is based on the following data standards:

A - Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods are certainly to be used as a guide.

B - Tests that are performed by a generally sound methodology but lack enough detail for adequate validation.

C - Tests that are based on an untested or new methodology or that lack a significant amount of background data.

D - Tests that are based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

An A-rated test may be a source test, a material balance, or some other methodology, as long as it is generally accepted as a sound method of measuring emissions from that source.

In the ideal situation, a large number of A-rated source test data sets representing a cross section of the industry are reduced to a single value for each individual source by computing the arithmetic mean of each test set. The emission factor is then computed by calculating the arithmetic mean of the individual source values. Alternatively, regression analysis is used to derive a predictive emission factor equation for the entire A-rated test set. No B-, C-, or D-rated test sets are used in the calculation of the emission factor because the number of A-rated tests is sufficient. This ideal method of calculating an emission factor is not always possible because of lack of A-rated data.

If the number of A-rated tests is so limited that inclusion of B-rated tests would improve the emission factor, then B-rated test data are included in the compilation of the arithmetic mean. No C- or D-rated test data are averaged with A- or B-rated test data. The rationale for inclusion of any B-rated test data is documented in the background information.

If no A- or B-rated test series are available, the emission factor is the arithmetic mean of the C- and D-rated test data. The C- and D-rated test data are used only as a last resort, to provide an order-of-magnitude value.

In AP-42, the reliability of these emission factors is indicated by an overall Emission Factor Rating ranging from A (excellent) to E (poor). These ratings take into account the type and amount of data from which the factors were calculated, as follows:

- **A - Excellent**. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough to minimize variability within the source category population.
- **B - Above average**. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- **C - Average.** Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- **D - Below average.** Developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor should be footnoted.

- **E - Poor.** Developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

Because the rating of an emission factor is subjective, the reasons for each rating are documented in the background information.

3.2 SOURCE TESTING METHODS FOR DIRECT EMISSION MEASUREMENT

Rather than relying on the use of published emission factors, especially for those sources of fugitive particulate emissions revealed as the most significant in the preliminary emissions inventory, it may be desirable to conduct source testing. This verifies the rates of uncontrolled emissions from the most important sources and establishes the relative importance of each of those sources. In addition, source testing would provide valuable data on the emission characteristics of each source, which in turn would aid considerably in selecting the most suitable control method for each source.

This section summarizes the methods for field measurement of mass emission rates and particle size distributions.

3.2.1 Mass Emissions Measurement

Fugitive particulate emission rates and particle size distributions are difficult to quantify because of the diffuse and variable nature of such sources and the wide range of particle size involved (including particles which deposit immediately adjacent to the source). Standard source testing methods, which are designed for application to confined flows under steady-state, forced-flow conditions, are not suitable for measurement of fugitive emissions unless the plume can be drawn into a forced-flow system.

For field measurement of fugitive mass emissions, four basic techniques have been defined:

1. The **quasi-stack** method involves capturing the entire particulate emissions stream with enclosures or hoods and applying conventional source testing techniques to the confined flow.
2. The **roof monitor** method involves measurement of particulate concentrations and airflows across well defined building openings such as roof monitors, ceiling vents, and windows, followed by calculation of particulate mass flux exiting the building.
3. The **upwind-downwind** method involves measurement of upwind and downwind particulate concentrations, utilizing ground based samplers under known meteorological conditions, followed by calculation of source strength (mass emission rate) with atmospheric dispersion equations.
4. The **exposure profiling** method involves simultaneous, multipoint measurements of particulate concentration and wind speed over the effective cross-section of the plume, followed by calculation of net particulate mass flux through integration of the plume profiles.
5. The **wind tunnel** method involves the use of a portable open-floored wind tunnel for in situ measurement of emissions from representative surfaces under predetermined wind conditions.

Each of these methods will be discussed below.

Quasi-Stack Method (Figure 3-1)[1]

In effect, the quasi-stack method converts a fugitive emission source to a conventional ducted source. Because it is usually impractical to enclose an open dust source or capture its entire emissions plume, the quasi-stack method is generally limited in applicability to process sources.

The quasi-stack method qualifies as a sound methodology only if evidence is provided in the test report as to the fact that the enclosure or

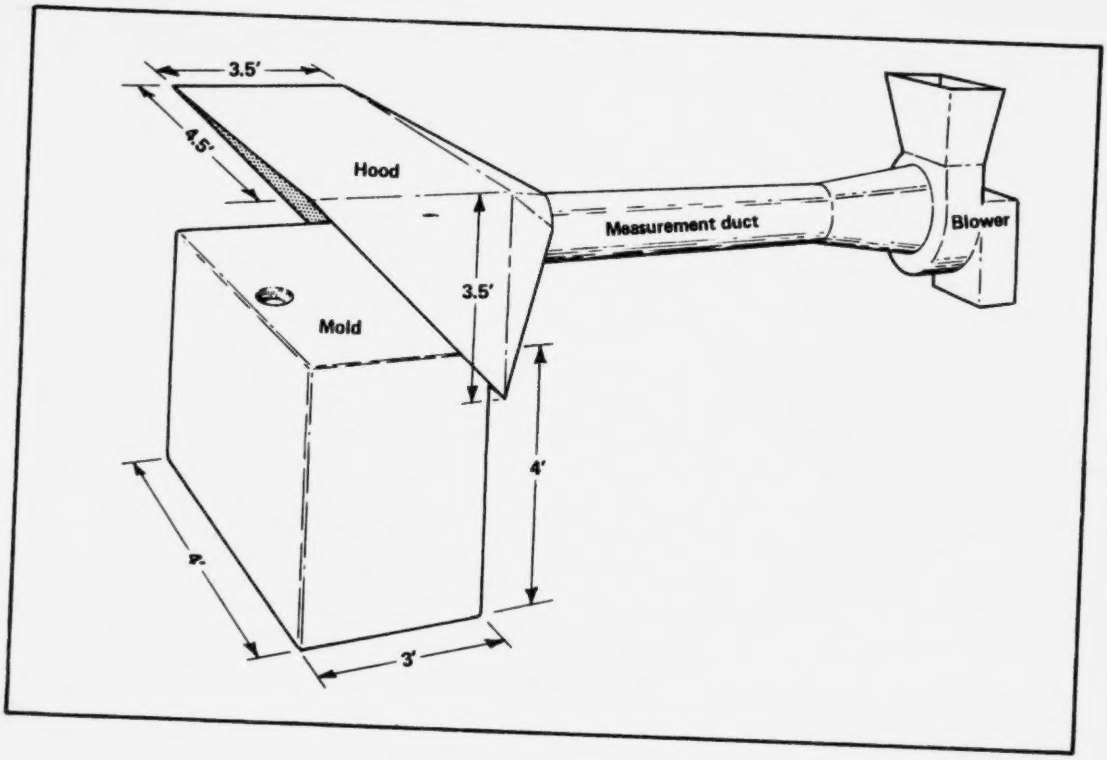
3.5'
4.5'
Hood
Measurement duct
Blower
3.5'
Mold
4'
9'
3'

Figure 3-1. Illustration of quasi-stack method[1]

hood is capturing the entire emissions stream without affecting the emission rate. In addition, an accepted sampling technique (e.g., Method 5) must be used to quantify the emission rate, taking steps to deal with special problems associated with highly fluctuating emissions.

Roof-Monitor Method (Figure 3-2)[2]

The roof monitor method is similar to the quasi-stack method in that it utilizes the building ventilation system to direct the emissions stream to the sampling location. Usually this method is practical only for high temperature processes which produce buoyant plumes.

The roof-monitor method qualifies as a sound methodology only if flows and concentrations can be adequately characterized within building discharge openings. Also, it must be shown that plume interference from other sources in the same building is not occurring. Finally, as with the quasi-stack method, the test report must describe how special problems associated with highly fluctuating emissions (and, in the case of natural ventilation, fluctuating ambient winds) were dealt with.

Upwind/Downwind Method (Figure 3-3)[6]

The basic procedure of the upwind-downwind method involves the measurement of particulate concentrations both upwind and downwind of the pollutant source. The number of required upwind sampling instruments depend on the isolability of the source operation of concern (i.e., the absence of interference from other sources upwind). Although at least five downwind particulate samplers must be operated during a test, increasing the number of downwind instruments improves the reliability in determining the emission rate by providing better plume definition. In order to reasonably define the plume emanating from a point source, instruments need to be located at two downwind distances and three crosswind distances at a minimum. The same sampling requirements pertain to line sources except that measurements at multiple crosswind distances are not required.

After the concentration(s) measured upwind are subtracted from the downwind concentrations, the net downwind concentrations are input to dispersion equations (normally of the Gaussian type). The dispersion equations are used to back-calculate the particulate emission rate required to

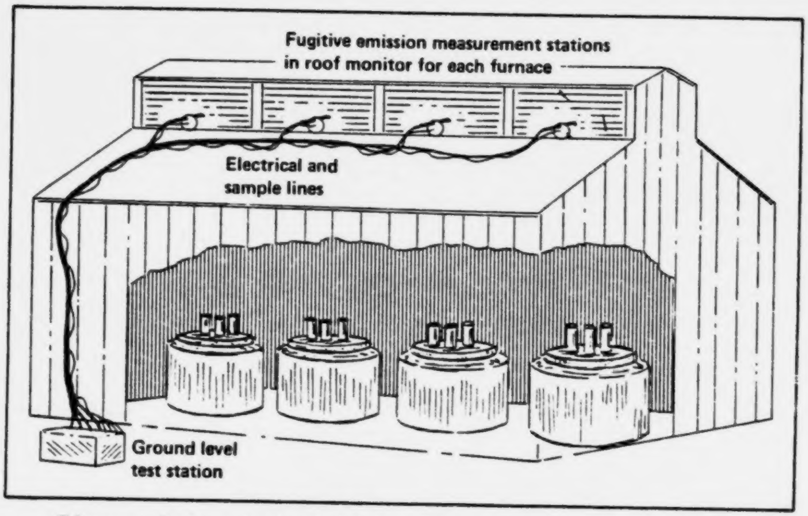
Fugitive emission measurement stations
in roof monitor for each furnace
Electrical and
sample lines
Ground level
test station

Figure 3-2. Illustration of roof monitor method[2]

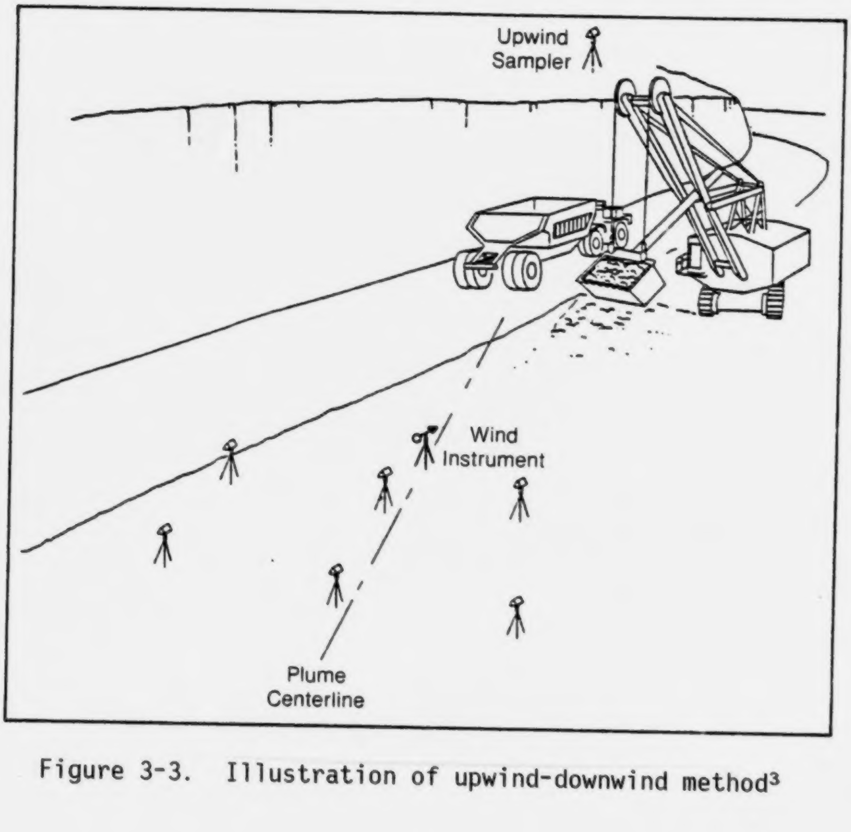
Upwind
Sampler
Wind
Instrument
Plume
Centerline

Figure 3-3. Illustration of upwind-downwind method[3]

generate the pattern of downwind concentrations. A number of meteorological parameters must be concurrently recorded for input to this dispersion equation. At a minimum the wind direction and speed must be recorded on-site.

Exposure Profiling Method (Figure 3-4)[4]

The exposure profiling method uses the profiling concept that is the basis for conventional (ducted) source testing, in much the same manner as do the quasi-stack method and roof monitor methods. The difference is that in the case of exposure profiling, the ambient wind directs the plume to the sampling array. The passage of airborne particulate matter immediately downwind of the source is measured directly by means of simultaneous multipoint sampling of particulate concentration and wind velocity over the effective cross section of the fugitive emissions plume. For measurement of nonbuoyant fugitive emissions, profiling sampling heads are distributed over a vertical network positioned just downwind (usually about 5 m) from the source. Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing about 90% of the total mass flux (exposure). A vertical line grid of at least three samplers is sufficient for measurement of emissions from line or moving point sources while a two-dimensional array of at least five samplers is required for quantification of fixed virtual point source emissions. At least one upwind sampler must be operated to measure background concentration, and wind speed must be measured concurrently on-site.

Unlike the upwind/downwind method, exposure profiling uses a mass-balance calculation scheme rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model. The mass of airborne particulate matter emitted by the source is obtained by spatial integration of distributed measurements of particulate flux, after subtraction of the background contribution. The exposure is the point value of the flux (concentration of airborne particulate accumulated over the time of measurement).

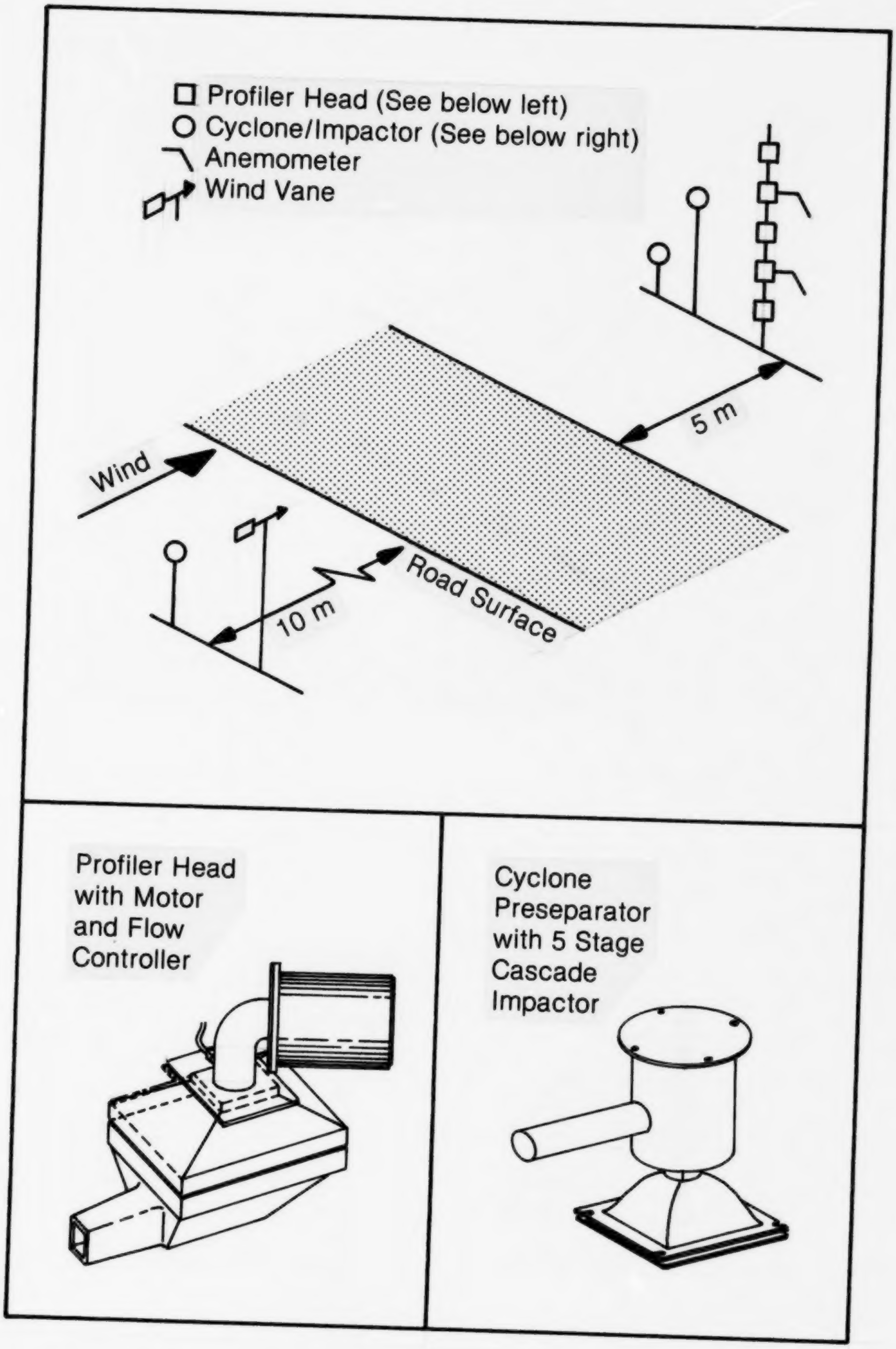
☐ Profiler Head (See below left)
○ Cyclone/Impactor (See below right)
Anemometer
Wind Vane
Wind
5 m
10 m
Road Surface
Profiler Head with Motor and Flow Controller
Cyclone Preseparator with 5 Stage Cascade Impactor

Figure 3-4. Illustration of exposure profiling method[4]

Wind Tunnel Method (Figure 3-5)[5]

The wind tunnel method utilizes a portable pull-through wind tunnel with an open-floored test section placed directly over the surface to be tested. Air is drawn through the tunnel at controlled velocities. The exit air stream from the test section passes through a circular duct fitted with a sampling probe at the downstream end. Air is drawn through the probe by a high-volume sampling train. This technique provides for precise study of the wind erosion process with minimal interference from background sources.

3.2.2 Particle Sizing

High-volume cascade impactors with glass fiber impaction substrates, which are commonly used to measure mass size distribution of atmospheric particulate, may be adapted for sizing of fugitive particulate emissions. A cyclone preseparator (or other device) is needed to remove coarse particles which otherwise would be subject to particle bounce within the impactor causing fine particle bias. Once again, the sampling intake should be pointed into the wind and the sampling velocity adjusted to the mean local wind speed by fitting the intake with a nozzle of appropriate size.

The EPA version of the dichotomous sampler, which is virtually free of particle bounce problems, is useful for quantification of fine particle mass concentrations. This sampler was designed with a symmetrical size-selective inlet (having a particle size cutpoint of 15 μmA) which is insensitive to wind speed or direction. However, this device operates at a low flow rate (1 cu m/hr) yielding only 0.024 mg of sample in 24 hr for each 1.0 $\mu g/m^3$ of IP concentration. Thus, an analytical balance of high precision is required to determine mass concentrations below and above the fine particulate (2.5 μm) cutpoint (the minimum in the typical bimodal size distribution of atmospheric particulate).

The size-selective inlet for a standard high-volume sampler is also designed to capture particulate matter smaller than 15 μmA. This unit is much less wind sensitive than the dichotomous sampler but it does not provide a cutpoint at 2.5 μm. However, it can be adapted for use with a high volume cascade impactor to define a mass size distribution of particles which penetrate the sampler inlet. Recently, size-selective inlets with 10 μmA

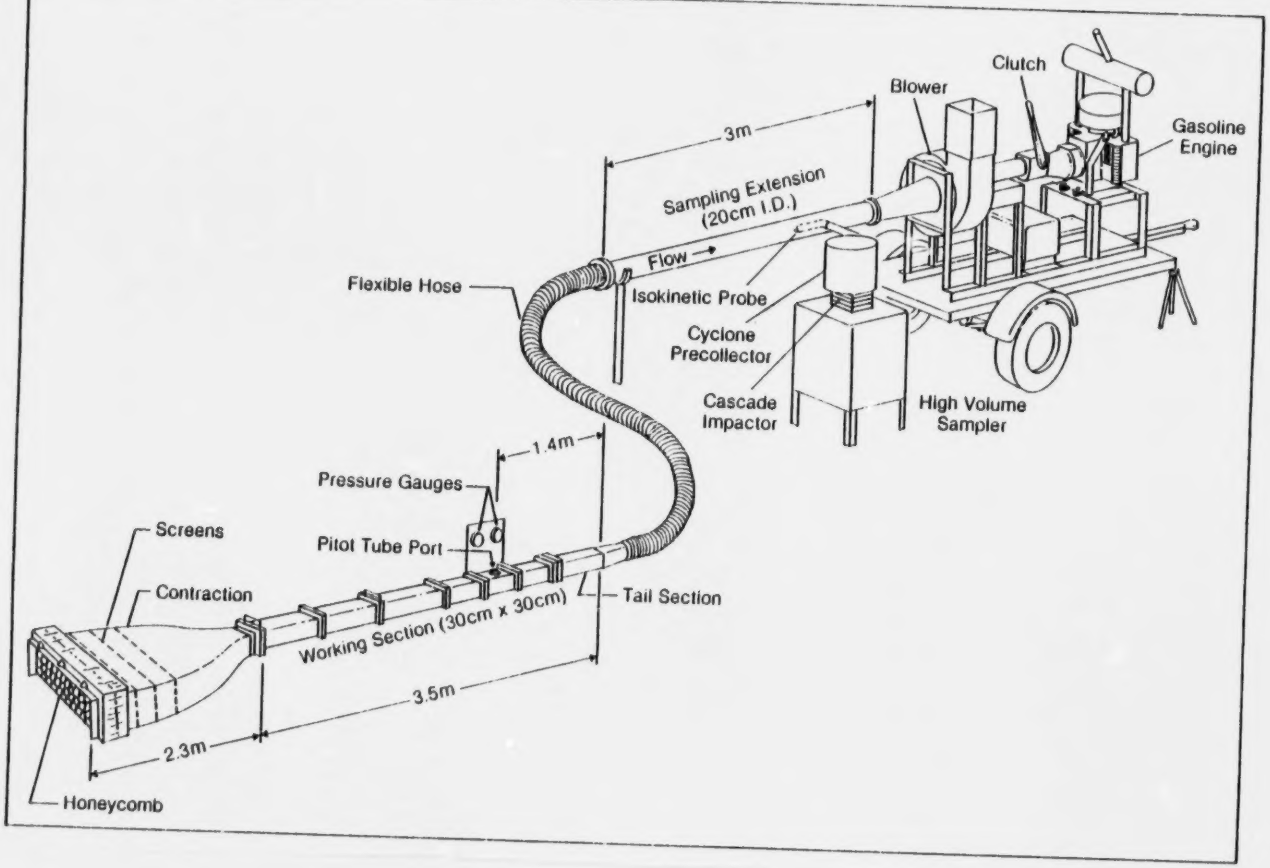
Clutch
Blower
Gasoline Engine
3m
Sampling Extension (20cm I.D.)
Flow →
Flexible Hose
Isokinetic Probe
Cyclone Precollector
Cascade Impactor
High Volume Sampler
1.4m
Pressure Gauges
Pitot Tube Port
Screens
Contraction
Tail Section
Working Section (30cm x 30cm)
3.5m
2.3m
Honeycomb

Figure 3-5. Illustration of wind tunnel method[5]

cutpoints have become available for both dichotomous samplers and high-volume samplers.

Another particle sizing technique gaining some recent prominence is microscopy. Microscopes used in particle sizing include optical or light microscopes, transmission electron microscopes (TEM), and scanning electron microscopes (SEM). Optical microscopy is useful in determining particle size for particles greater than about 0.25 μm in diameter. Electron microscopes provide the ability to size particles greater than about 0.001 μm in diameter.

Of the many techniques available to size particles by their physical dimensions as observed through the microscope, the most common approach is the projected area technique. The particle size is set equal to the diameter of a circle with the same area as the projected area of the particle. A minimum of 300 particles is usually required in order to determine a size distribution (with about 9 categories). Because this work requires several tedious hours to perform manually, attempts to automate the process have naturally arisen. Examples are the use automatic image analysis for optical microscopy, and computer controlled scanning electron microscopy (CCSEM). Both of these advances incorporate the projected area approach.

3.3 EVALUATION OF CONTROL SYSTEM PERFORMANCE

As in the case of uncontrolled emission factors, the efficiency of an existing (or potential) control system can either be (a) established by direct field measurements, or (b) estimated based on performance obtained from the literature. However, this situation is one step more complex in that determination of control performance requires knowledge of both the uncontrolled and the controlled emission rates. This subject will be explored in detail at the end of Chapter 4 which identifies the various control alternatives for sources of fugitive particulate emissions.

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3. Axetell, K. Jr. and C. Cowherd, Jr. Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources, Volumes I and II. EPA-600/7-84-048, NTIS No. PB84-170802, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1984.

4. Cowherd, C. Jr., et al. Development of Emissions Factors for Fugitive Dust Sources. EPA-450/3-74-037, NTIS No. PB238262, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

5. Cuscino, T., G. Muleski and C. Cowherd, Jr. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. EPA-600/2-83-110, NTIS No. PB84-110568, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1983.

6. Kolnsberg, H. J. Technical Manual for Measurement of Fugitive Emissions: Upwind/Downwind Sampling Method for Industrial Emissions. EPA-600/2-76-089a, NTIS No. PB253092, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1976.

SECTION 4
IDENTIFICATION OF CONTROL ALTERNATIVES

Typically, there are several options for control of fugitive particulate emissions from any given source. This is clear from the mathematical equation used to calculate the emission rate:

$$R = M\ e\ (1 - c)$$

where:

R = estimated mass emission rate

M = source extent

e = uncontrolled emission factor, i.e., mass of uncontrolled emissions per unit of source extent

c = fractional efficiency of control

To begin with, because the uncontrolled emission rate is the product of the source extent and uncontrolled emission factor, a reduction in either of these two variables produces a proportional reduction in the uncontrolled emission rate.

Although the reduction of source extent results in a highly predictable reduction in the uncontrolled emission rate, such an approach in effect usually requires a change in the process operation. Frequently, reduction in the extent of one source may necessitate the increase in the extent of another, as in the shifting of vehicle traffic from an unpaved road to a paved road. The option of reducing source extent is beyond the scope of this manual and will not be discussed further.

The reduction in the uncontrolled emission factor may be achieved by process modifications (in the case of process sources) or by adjusted work practices (in the case of open sources). The degree of the possible reduction of the uncontrolled emission factor can be estimated from the known dependence of the factor on source conditions that are subject to alteration. For open dust sources, this information is embodied in the predictive emission factor equations for fugitive dust sources as presented in Section 11.2 of EPA's "Compilation of Air Pollutant Emission Factors" (AP-42).

The reduction of source extent and the incorporation of process modifications or adjusted work practices are preventive techniques for control of fugitive particulate emissions. In addition, there are a variety of "add-on" measures which can be used for (a) **prevention** of the creation and/or release of particulate matter into the atmosphere, or (b) **capture and removal** of the particles after they have become airborne.

Selection of suitable control methods depends on the mechanism(s) which generate the particulate emissions and the specific source involved. The methods used to control process sources of fugitive particulate emissions generally take a much different approach from those applied to open dust sources. Differences in source configuration, process requirements, and emissions stream characteristics also affect selection of specific controls.

This section provides the information needed to identify feasible control techniques for specific sources of fugitive particulate emissions. The basic characteristics of each type of control technique are described, and the types of emission sources amenable to control by the techniques are discussed. Control techniques applicable to the major sources of fugitive particulate emissions defined in Section 2 are identified.

The section is divided into four parts. The first two parts describe preventive and capture/removal control techniques, respectively. The third part identifies the types of controls applicable to open dust and process sources. Finally, the fourth part addresses the scheme used for quality rating of control performance data.

4.1 PREVENTIVE MEASURES

Preventive measures include those measures which prevent or substantially reduce the injection of particles into the surrounding air environment.

Preventive measures are independent of whether the particulate is emitted directly into the ambient air, or into the interior of a building. The main types of preventive measures include:

- Passive enclosures (full or partial),
- Wet suppression,
- Stabilization of unpaved surfaces,
- Paved surface cleaning,
- Work practices, and
- Housekeeping.

Descriptions of control techniques within these five categories are presented below.

4.1.1 Passive Enclosures

A common preventive technique for the control of fugitive particulate emissions is to either fully or partially enclose the source. Enclosures preclude or inhibit particulate matter from becoming airborne due to the disturbance created by ambient winds or by mechanical entrainment resulting from the operation of the source itself. Enclosures also help contain those emissions which are generated. Enclosures can consist of either some type of permanent structure or a temporary arrangement. The particular type of enclosure used is dependent on the individual source characteristics and the degree of control required.

Permanent enclosures are designed to either partially or completely enclose the source by the construction of a building or other structure. Worker safety and housekeeping can become problems in the vicinity of the fugitive emission source controlled by a passive (nonevacuated) enclosure. Types of sources commonly controlled by total enclosures include aggregate storage (bins rather than piles) and external conveyor transport.

Since temporary enclosures take many forms, they are difficult to classify generically. Examples of temporary enclosures are flexible tarpaulin covers over the hatchways of large ocean-going vessels during the loading of grain, or flexible shrouds around truck loading spouts.

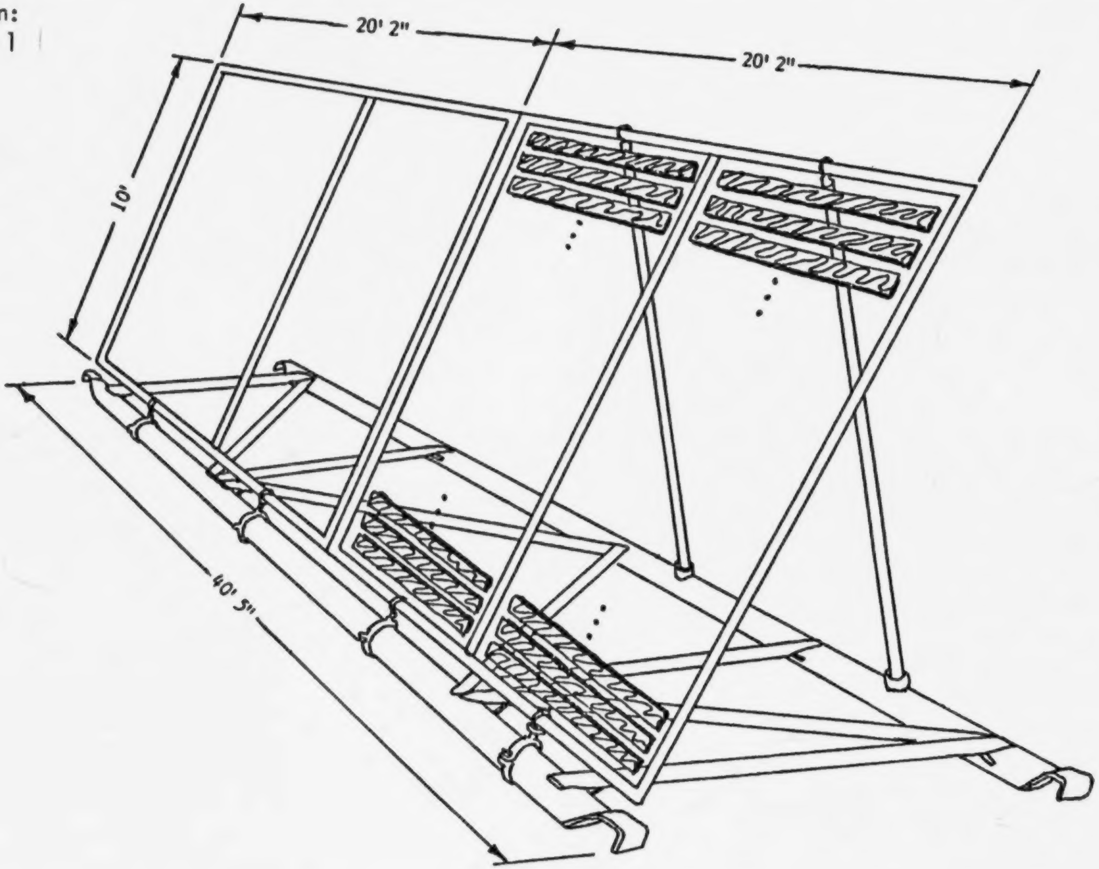
A novel variation to the source enclosure method for the control of fugitive particulate emissions involves the application of porous wind fences (also referred to as wind screens). Porous wind fences have been shown to significantly reduce emissions from active storage piles and exposed ground areas. The principle employed by wind screens is to provide a sheltered region behind the fenceline where the mechanical turbulence generated by ambient winds is significantly reduced. The downwind extent of the protected area is many times the physical height of the fence. This sheltered region provides for both a reduction in the wind erosion potential of the exposed surface in addition to allowing the gravitational settling of the larger particles already airborne. The application of wind screens along the leading edge of active storage piles seems to be one of the few good control options which are available for this particular source. A diagram of one type of portable wind screen used at a coal-fired power plant is shown in Figure 4-1.[1]

4.1.2 Wet Suppression

Wet suppression systems apply either water, a water solution of a chemical agent, or a micron-sized foam to the surface of the particulate generating material. This measure prevents or suppresses the fine particles contained in that material from leaving the surface and becoming airborne. If fine water sprays are used to control dust after it has become suspended, this is referred to as plume aftertreatment. Plume aftertreatment (e.g., charged fog) is not a preventive measure but a capture/removal method as discussed below.

The chemical agents used in wet suppression systems can be either surfactants or foaming agents for materials handling and processing operations (e.g., crushers, conveyors) or various types of dust palliatives applied to unpaved roads. In either case, the chemical agent acts to agglomerate and bind the fines to the aggregate surface, thus eliminating or reducing its emissions potential. Each major type of wet suppression method will be described individually.

Wet suppression systems using plain water have been utilized for many years on a variety of sources such as crushing, screening, and materials


20' 2"
20' 2"
10'
40' 5"

Adapted from:
Reference 1

Figure 4-1. Diagram of a portable wind screen[1]

transfer operations, as well as unpaved roads. For most mechanical equipment, wet suppression involves the use of one or more water sprays to wet the material prior to processing. This technique is usually only temporarily effective, requiring repeated application throughout the process flow. An illustration of a wet suppression system used at a crusher discharge point is shown in Figure 4-2.[2]

It should be noted that, in addition to possible freezing problems in the winter, wet suppression with plain water can be used only on those bulk materials which can tolerate a relatively high surface moisture content. In the arid West, wet suppression is not always practical due to inadequate water supplies.

In the case of unpaved roads and parking lots, water is generally applied to the surface by a truck or some other type of vehicle utilizing either a pressurized or a gravity flow system. Again, watering of unpaved roads is only a temporary measure, necessitating repeated application at regular intervals.

To improve the overall control efficiency of wet dust suppression systems, wetting agents can be added to the water to reduce the surface tension. The additives allow particles to more easily penetrate the water droplet and increase the number of droplets, thus increasing the surface area and contact potential.

One of the more recently developed methods used to augment wet suppression techniques is the use of foam injection to control dust from materials handling and processing operations. The foam is generated by adding a proprietary surfactant compound to a relatively small quantity of water which is then vigorously mixed to produce a small bubble, high energy foam in the 100- to 200-μm size range. The foam uses very little liquid volume and, when applied to the surface of a bulk material, wets the fines more effectively than does untreated water. Foam has been used with good success for controlling the emissions from belt transfer points, crushers, and storage pile load-in.

4.1.3 Stabilization of Unpaved Surfaces

Release of particulate from unpaved surfaces can be reduced or prevented by stabilization of those surfaces. Sources which have been controlled in

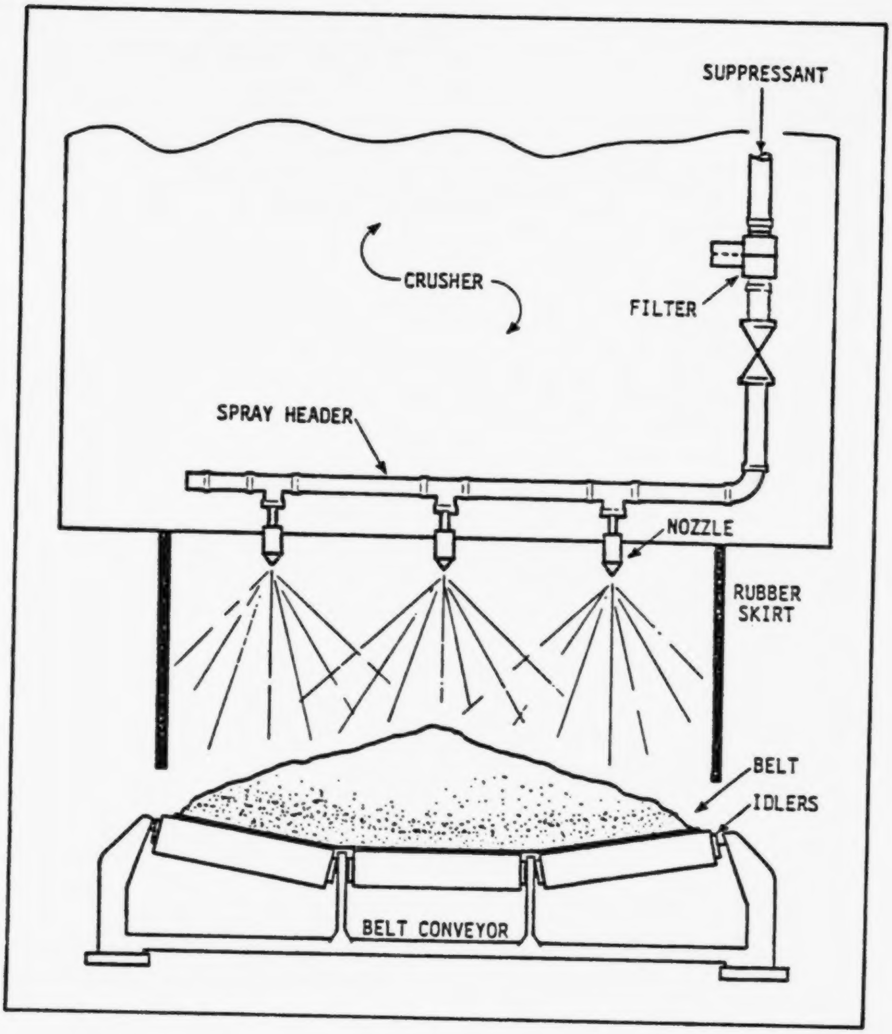

SUPPRESSANT
CRUSHER
FILTER
SPRAY HEADER
NOZZLE
RUBBER SKIRT
BELT
IDLERS
BELT CONVEYOR

Figure 4-2. Wet suppression system at a crusher discharge point[2]

this manner include unpaved roads and parking lots, active and inactive storage piles, and open areas. Stabilizing mechanisms which have successfully employed include chemical, physical, and vegetative controls. Each of these control types is described below.

The use of chemical dust suppressants for the control of fugitive emissions from unpaved roads has received much attention in the past several years. Chemical suppressants can be classified into six generic categories. These are: (a) salts (i.e., $CaCl_2$ and $MgCl_2$); (b) lignin sulfonate; (c) wetting agents; (d) latexes; (e) plastics; and (f) petroleum derivatives.

Salts, which are usually obtained from natural brine deposits, provide dust control by absorbing and retaining moisture in the surface material. Wetting agents enhance the mitigative effects of watering by lowering the surface tension of water, thereby causing more rapid penetration into the surface material. The remaining dust suppressants of both natural and synthetic origin function by binding the fines to larger aggregates in the surface material.

Chemical dust suppressants are generally applied to the road surface as a water solution of the agent. The degree of control achieved is a direct function of the application intensity, dilution ratio, and frequency (number of applications/unit time) of the chemical applied to the surface and also depends on the type and number of vehicles using the road. Chemical agents have also been proven to be effective as crusting agents for inactive storage piles and for the stabilization of exposed open areas. In both cases, the chemical acts as a binder to reduce the wind erosion potential of the aggregate surface. A typical pressurized spray truck used for the application of chemical suppressants to unpaved surfaces is shown in Figure 4-3.[3]

Physical stabilization techniques can also be used for the control of fugitive emissions from unpaved surfaces. Physical stabilization includes any measure, such as compaction of fill material at construction and land disposal sites, which physically reduces the emissions potential of a source resulting from either mechanical disturbance or wind erosion.

The most notable form of physical stabilization of current interest involves the use of civil engineering fabrics or "road carpet" for unpaved roads. In practice, the road carpet fabric is laid on top of a properly

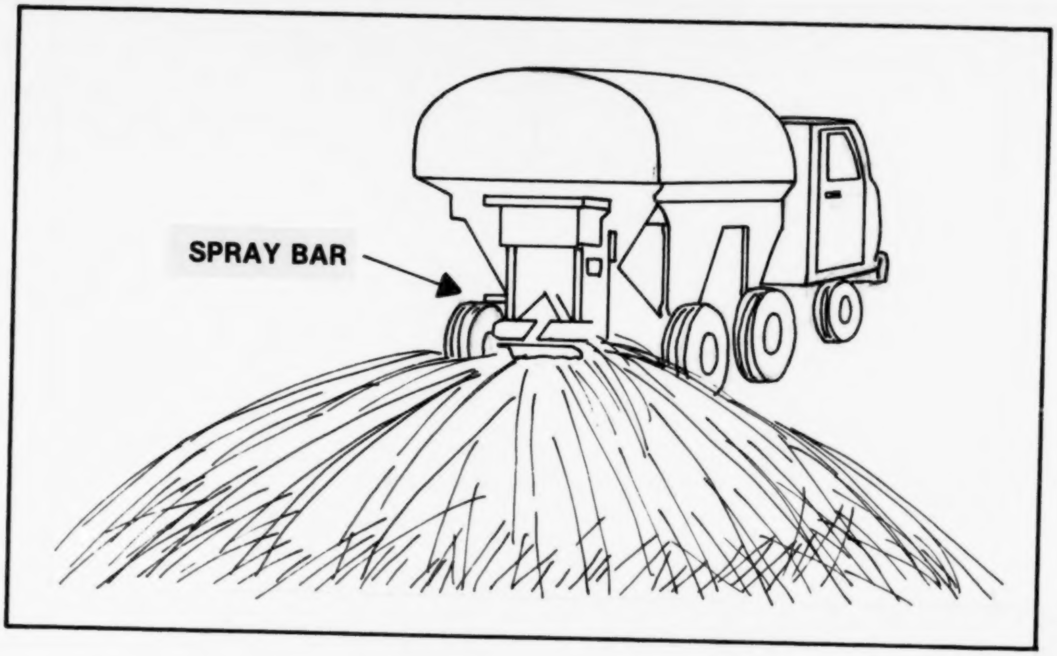


Figure 4-3. Pressurized spray truck for application of chemical dust suppressants

prepared road base just below a layer of coarse aggregate (ballast). The fabric sets up a physical barrier such that the fines (< 75 µm in diameter) are prevented from contaminating the ballast layer. These smaller particles are now no longer available for resuspension and saltation resulting from the separation of the fines from the ballast. The fabric is also effective in distributing the concentrated stress from heavy-wheeled traffic over a wider area.

Vegetative stabilization involves the use of various species of flora to control wind erosion from exposed surfaces. Vegetative techniques can be used only when the material to be stabilized is inactive and will remain so for an extended period of time. It is often difficult to establish a vegetative cover over materials other than soil because their physical or chemical characteristics are not conducive to plant growth. Resistant strains which can tolerate the composition of the host material sometimes must be developed.

4.1.4 Paved Surface Cleaning

Other than housekeeping, the only method available to reduce the surface loading of fine particles on paved roads is through some form of street cleaning practice. Street sweeping does remove some debris from the pavement thus preventing it from becoming airborne by the action of passing vehicles; but it can also generate significant amounts of finer particulate by the mechanical action used to collect the material.

The three major methods of street cleaning are mechanical cleaning, vacuum cleaning, and flushing. Mechanical street sweepers utilize large rotating brooms to lift the material from the pavement and discharge it into a hopper for later disposal. Broom sweepers are usually effective in picking up only relatively large debris, with a significant portion of the surface material being suspended in the wake of the vehicle.

Vacuum sweepers remove the material from the street surface by drawing a suction on a pickup head which entrains the particles in the moving air stream. The debris is then deposited in a hopper, and the air is exhausted to the atmosphere. Vacuum units also use gutter brooms to loosen and deflect debris so that it can be picked up. They also have an additional broom which loosens the street dirt and pushes it toward the vacuum nozzles where it is drawn into the storage compartment. A filter system traps the dust and confines it to the sweeper hopper.

The regenerative sweeper is a vacuum unit with certain significant differences. Cleaning is accomplished by a pickup head with rubber dust curtains at the front. The sweeper has a 9-ft cleaning width. A blower directs a strong blast of air across the pickup head, and the suction from the blower draws the debris into the hopper through a dust separator. Thus, the air circulates continuously through the vacuum sweeper mechanism with no air or dust exhausted to the atmosphere.

Street flushers hydraulically remove debris from the surface to the gutter and eventually to the storm sewer system through the use of high pressure water sprays. Water storage tanks on flushers vary in capacity from 800 to 3,500 gal. Flushers have large nozzles, individually controlled, which can be directed either toward the gutter or in a forward direction. Water emerges from the nozzles at pressures of up to 100 psig. This pressure is usually sufficient to scour most debris on the pavement. Flushers have numerous operational disadvantages including the consumption of large quantities of water with the associated potential for water pollution problems. A diagram of both a typical broom sweeper and a regenerative air sweeper is shown in Figure 4-4.[3]

4.1.5 Work Practices (Open Dust Sources)

Work practices may be used to reduce fugitive particulate emissions from an open dust source by reducing the uncontrolled emission factor. Work practices focus on the operation of equipment used to transport, store, and transfer aggregate materials. The equipment related correction parameters appearing in the AP-42 emission factor equations for open dust sources identify the work practice options. In the case of unpaved and paved travel surface, emissions can be reduced by decreasing vehicle speed and weight. For materials handling operations, emissions can be reduced by decreasing drop height and by increasing bucket capacity. Finally, emissions from wind erosion can be reduced by decreasing the size of the active area of a storage pile or exposed ground surface.

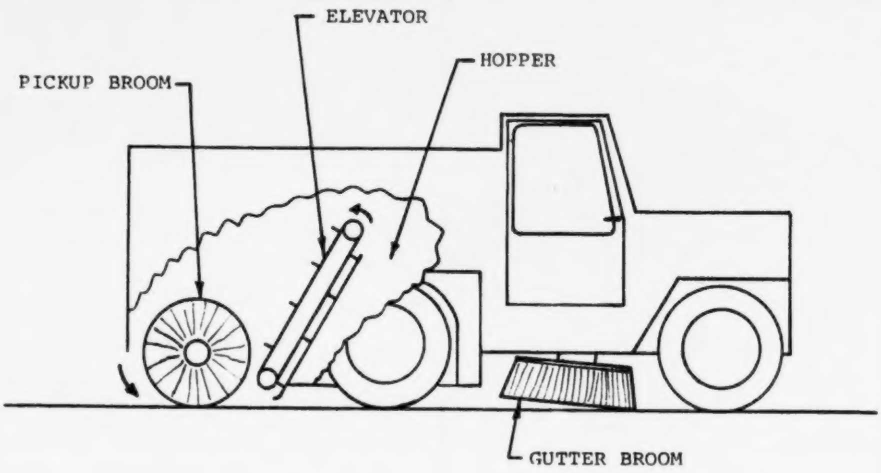
4.1.6 Housekeeping

Housekeeping generally refers to the removal of exposed dust producing materials on a periodic basis to reduce the potential for dust generation through the action of wind or machinery. Examples of housekeeping measures include: clean-up of spillage on travel surfaces (paved and unpaved); elimination of mud/dirt carryout onto paved roads at construction and demolition sites; and clean-up of material spillage at conveyor transfer points.

Any such method can be employed depending on the source, its operation, and the type of dust-producing material involved. A detailed evaluation is necessary on a case-by-case basis to determine what housekeeping measures can be employed.

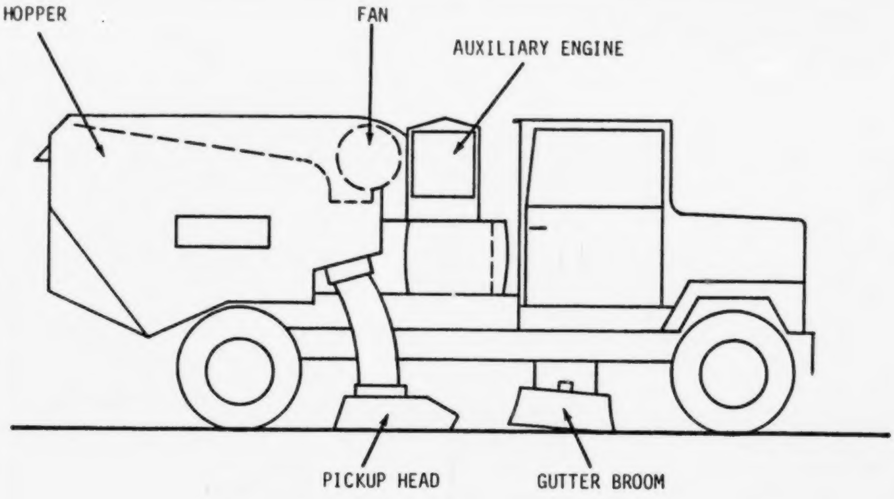
4.2 CAPTURE/REMOVAL METHODS

The second basic technique for the control of fugitive particulate emissions includes those methods which capture or remove the particles after they have become airborne. Again, this classification is irrespective



ELEVATOR
HOPPER
PICKUP BROOM
GUTTER BROOM

(a) Four-wheeled broom sweeper



HOPPER
FAN
AUXILIARY ENGINE
PICKUP HEAD
GUTTER BROOM

(b) Regenerative air vacuum sweeper

Figure 4-4. Diagrams of typical street cleaners[3]

of whether such emissions are generated inside or outside of a building. The major types of capture/removal processes include:

- Capture and collection systems, and
- Plume aftertreatment.

The various methods in both categories are described below.

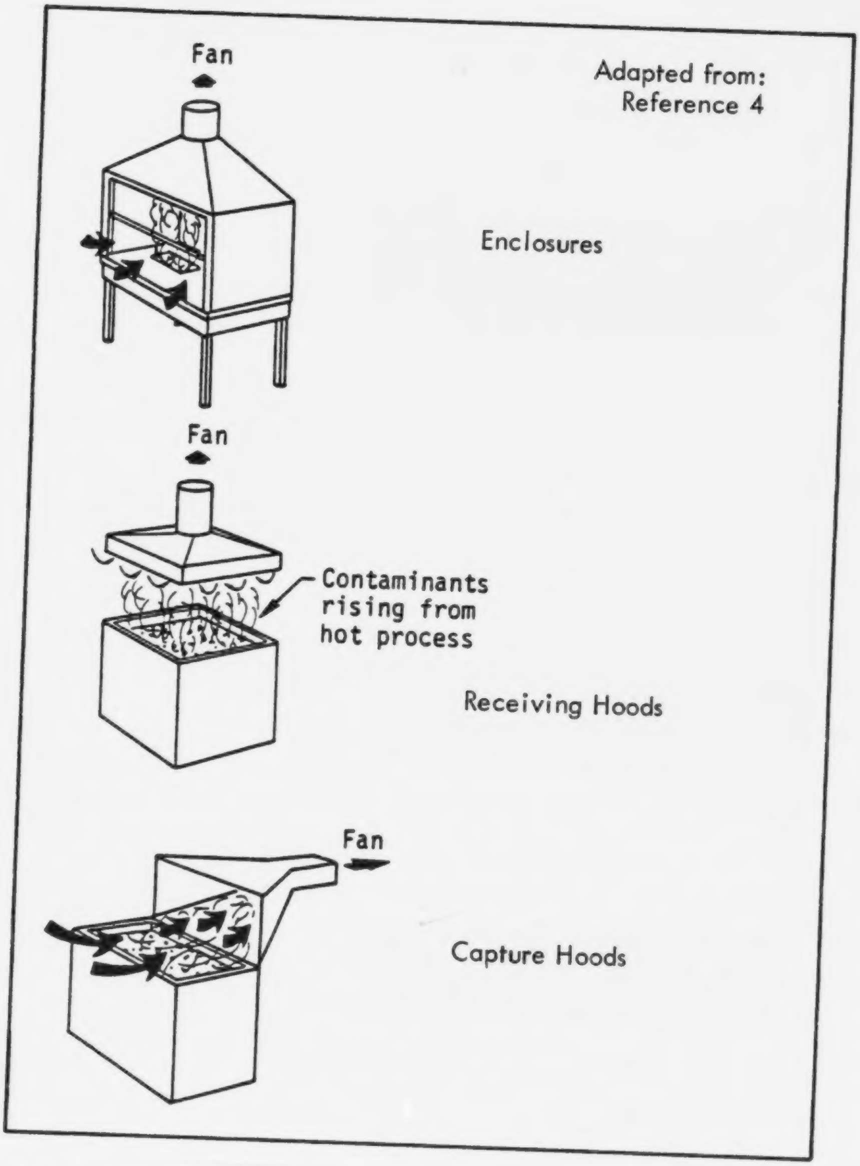
4.2.1 Capture and Collection Systems

Most industrial process fugitive emissions have traditionally been controlled by capture/collection, or industrial ventilation systems. These systems have three primary components: (a) a hood or enclosure to capture emissions that escape from the process; (b) a dust collector that separates entrained particulate from the captured gas stream; and (c) a ducting or ventilation system to transport the gas stream from the hood or enclosure to the air pollution control device.

A wide variety of capture mechanisms ranging from total enclosure of the source, to mobile high velocity low volume (HVLV) hoods, to total building evacuation have been employed. Capture devices (or hoods) generally can be classified as one of three types: enclosure, capture hood, or receiving hood. Each type is illustrated in Figure 4-5.[4]

Enclosures, partial or complete, surround the source as much as possible without interfering with process operations. Their predominant feature is that they prevent release of particulate to the atmosphere or working environment. The enclosure is equipped with one or more takeoff ducts to remove any particulate that is generated and to maintain a slight negative pressure in the enclosure. Examples of enclosures include enclosed shakeout operations in metal foundries, casings on bucket elevators used for aggregate material transfer, and building evacuation for secondary furnace control.

Capture hoods are located in such a manner that the process is external to the hood. Emissions are actually released to the atmosphere or plant environment and subsequently captured by the hood. Capture hoods have also been referred to as exterior hoods by some authors.


Fan
Enclosures
Fan
Contaminants rising from hot process
Receiving Hoods
Fan
Capture Hoods

Adapted from:
Reference 4

Figure 4-5. General types of capture devices (hoods)[4]

The operating principle of the capture hood is based on capture velocity. The control system must produce a sufficient air velocity at the emissions source to draw the emitted particles to the hood and "capture" the emissions stream. Examples of capture devices are side-draft hoods to capture secondary electric arc furnace emissions, push/pull side-draft hoods to control metal pouring emissions, and side-draft hoods control cleaning and finishing emissions.

In the case of receiving hoods, emissions from the process are also released to the atmosphere or plant environment prior to entering the hood. However, receiving hoods are designed to take advantage of the inherent momentum of some emissions streams. This momentum is generally a result to thermal buoyancy but also may be a result of inertia generated by the process (e.g., a grinding plume). The system does not need to generate a capture velocity, but it should be designed to exhaust a slightly greater velocity from the hood than the process delivers. Examples of receiving hoods include canopy hoods to capture secondary furnace emissions, close capture hoods located above metal pouring operations, and grinding wheel close capture hoods.

The selection of a suitable capture device is site-specific and depends on both the operating and emissions characteristics of the source. Factors influencing selection include location of the process with respect to other plant operations, degree of process movement (if any), space needed for worker or equipment access to the process, physical size of the operation or process, and momentum of the particulate plume due to buoyancy or inertia applied by the process.

Particulate matter is removed from the gas stream in capture/collection systems by one of four generic types of air pollution control devices: mechanical collectors (or cyclones), wet scrubbers, fabric filters, and electrostatic precipitators (ESPs). As with the capture device, selection of the air pollution control device is site-specific, depending on such factors as: degree of control required to meet regulations or enhance product recovery; availability of excess capacity from an existing control device; feasibility of designing a common device for multiple sources; and various characteristics of the emissions stream. Some of the more important emissions characteristics are particle size distribution, particle resistivity, gas temperature, corrosivity, and chemical composition.

The simplest, and most often neglected, component of the industrial ventilation system is the ductwork or transport system. The transport system must be designed to maintain adequate transport velocities in the ducts and be balanced with respect to pressure drop. Two of the most common causes of malfunctions of capture/collection systems are plugging of the ductwork because of inadequate transport velocities and unbalanced ventilation systems (from either poor design or improper operation) resulting in inadequate capture velocities or exhaust volumes at some processes.

A variation of the traditional capture/collection concept involves the use of air curtains or jets. Air curtains are usually used in those industrial processes which generate a buoyant plume to help isolate it and enhance capture by the emissions control system. One such system is a so-called "push/pull" arrangement. In such an arrangement, an air curtain consisting of a series of jets is used to contain and direct the plume toward some type of capture device. One such system is shown in Figure 4-6 for a copper converter.[5]

4.2.2 Plume Aftertreatment

Plume aftertreatment refers to any system which injects fine water droplets into a dust plume to capture and agglomerate the suspended particles (by impaction and/or electrostatic attraction) to enhance gravitational settling. Plume aftertreatment systems can use water sprays with or without the addition of a chemical surfactant as well as with or without the application of an electrostatic charge (charged fog).

Aftertreatment systems using plain water consist of one or more hydraulic (pressure) or pneumatic (two-fluid) nozzles which create a spray of fine water droplets. When sprayed into the dust plume, these droplets capture and settle the suspended dust particles. This technique has been used extensively for the control of respirable dust in underground mining and similar operations conducted above ground.

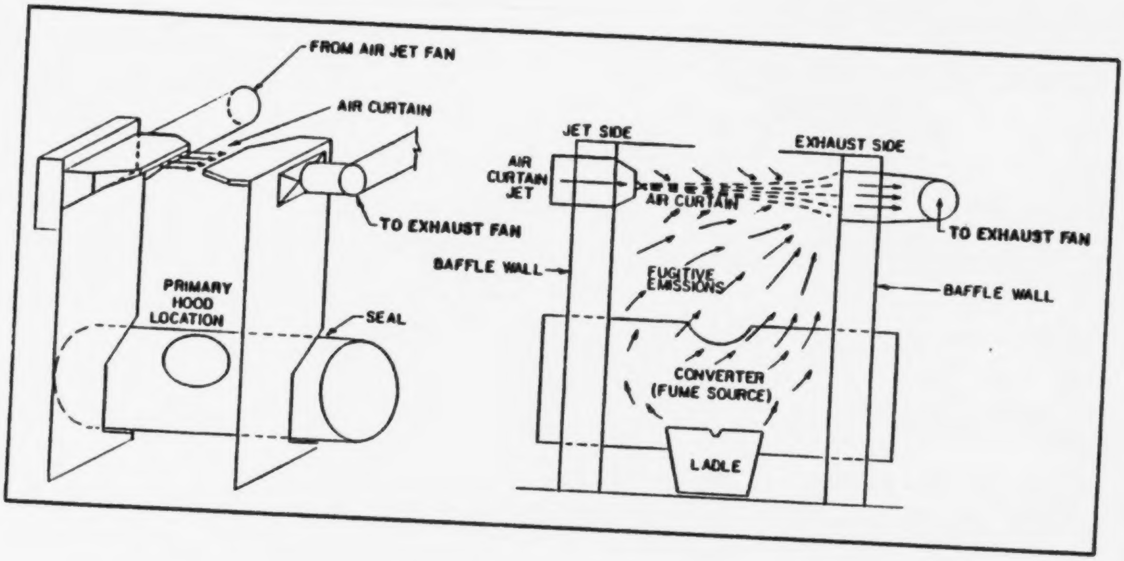
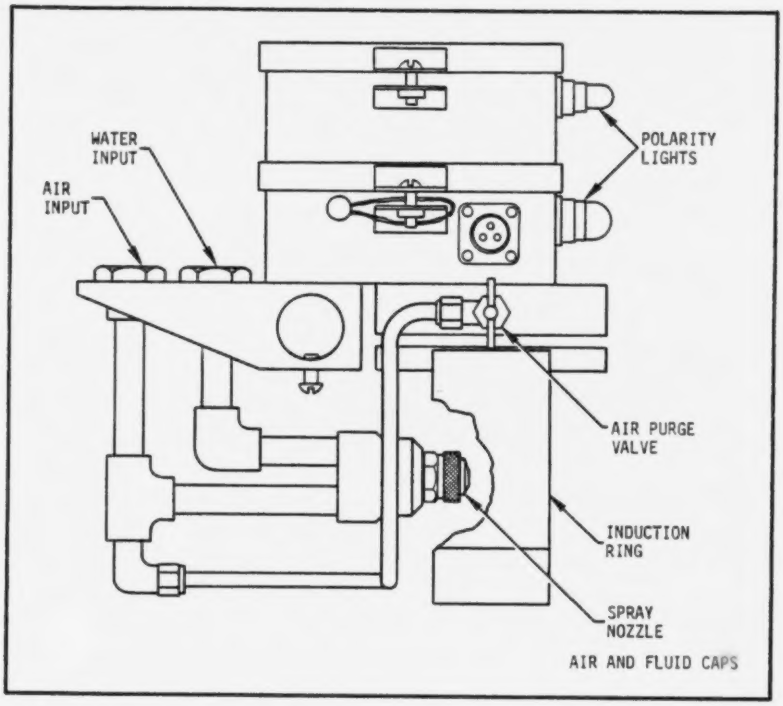

FROM AIR JET FAN
AIR CURTAIN
TO EXHAUST FAN
PRIMARY HOOD LOCATION
SEAL
JET SIDE
EXHAUST SIDE
AIR CURTAIN JET
AIR CURTAIN
TO EXHAUST FAN
BAFFLE WALL
FUGITIVE EMISSIONS
BAFFLE WALL
CONVERTER (FUME SOURCE)
LADLE

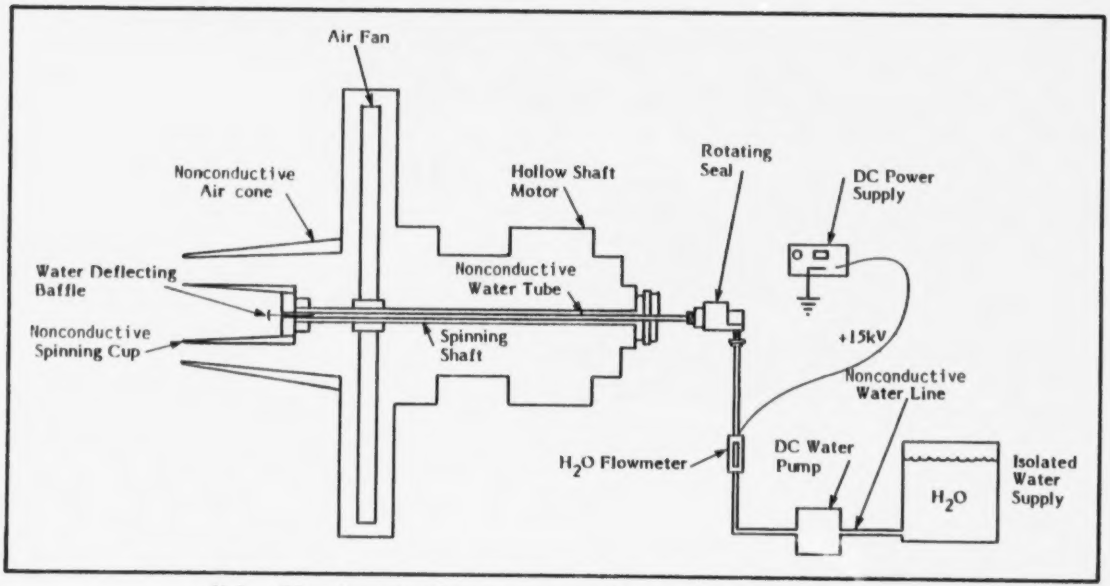
Figure 4-6. Converter air curtain control system[5]

In the past several years, a novel means involving the use of electrostatics has been developed to augment traditional water sprays for plume aftertreatment. Most anthropogenically produced particles normally acquire a slight electrostatic charge. By injecting a fog of oppositely charged water droplets into the plume, a significant enhancement in the capture and removal process can be achieved.

An electrostatic charge can be applied to a water spray by either of two means. Induction charging applies an electrostatic charge to the droplets by passing the spray through a ring which is isolated at a high voltage. The alternative is to charge the water prior to atomization by direct contact. Of the two methods, contact charging has proven to be much more effective in achieving a higher charge-to-mass ratio. Under heavy spray conditions, induction charging tends to charge only those droplets on the outside of the spray cone. Diagrams of electrostatic foggers using both induction and contact charging are shown in Figure 4-7.[6]


WATER INPUT
AIR INPUT
POLARITY LIGHTS
AIR PURGE VALVE
INDUCTION RING
SPRAY NOZZLE
AIR AND FLUID CAPS

(a) Electrostatic fogger using induction charging


Air Fan
Nonconductive Air cone
Hollow Shaft Motor
Rotating Seal
DC Power Supply
Water Deflecting Baffle
Nonconductive Water Tube
Nonconductive Spinning Cup
Spinning Shaft
+15kV
Nonconductive Water Line
H_2O Flowmeter
DC Water Pump
H_2O
Isolated Water Supply

(b) Electrostatic fogger using contact charging

Figure 4-7. Electrostatic foggers[6]

4.3 APPLICABILITY OF CONTROLS TO FUGITIVE EMISSIONS SOURCES

Open dust sources are generally controlled by preventive techniques rather than capture/removal techniques. Typical measures used include passive enclosures, wet suppression, stabilization, and surface cleaning. Table 4-1 identifies the types of control measures applicable to each of the generic open dust source categories identified in Section 2.

Process fugitive sources can be controlled by either preventive or capture/removal measures. Principal control measures include wet suppression, capture/collection systems, and plume aftertreatment. Table 4-2 identifies the types of control applicable to process fugitive emissions sources.

4.4 RATING OF PERFORMANCE DATA

In evaluating the quality of performance data, the first step is to locate the original source of the control efficiency value, whether it is based on test data or simply estimation. This may require several steps because of the practice of referencing a more recent (and presumably more credible) document rather than the original source of the value. If the value appears in a symposium paper, it is likely that there exists a more comprehensive companion report which provides a more complete basis for the quality evaluation.

The scheme used in this document for quality rating of control efficiency values is similar to the A through E rating model developed by EPA for AP-42 emission factors. The scheme entails the rating of test data quality followed by the rating of the adequacy of the data relative to the characterization of uncontrolled and controlled emissions.

To be assigned an A quality rating, a control efficiency value must be based on mass emission tests performed by a sound methodology and reported in enough detail for adequate validation. In addition, enough tests must be performed at appropriate sampling points to quantify the average uncontrolled and controlled mass emission rates for the specific source/control combination in question. Finally, values for the parameters needed to characterize the source operation and the control system must be reported.

TABLE 4-1. FEASIBLE CONTROL MEASURES FOR OPEN DUST SOURCES

Source category	Fugitive Emission Control Measure						
	Enclosures[a]	Wet suppression	Chemical stabilization	Physical stabilization	Vegetative stabilization	Surface cleaning	Capture/removal[b]
Unpaved roads		X	X	X			
Unpaved parking lots and staging areas		X	X	X			
Storage piles	X	X	X	X			
Paved streets and highways						X	
Paved parking lots and staging areas						X	
Exposed areas	X	X	X	X	X		
Batch drop operations[c]	X	X					X
Continuous drop operations[d]	X	X					X
Pushing (e.g., dozing, grading, scraping, etc.)		X	X				

[a] Includes full and partial enclosures as well as wind fences.

[b] Includes both capture/collection systems and plume aftertreatment.

[c] Includes operations such as front-end loaders, shovels, etc.

[d] Includes operations such as conveyor transfer, stacking/reclaiming, etc.

TABLE 4-2. PROCESS FUGITIVE PARTICULATE EMISSION SOURCES AND FEASIBLE CONTROL TECHNOLOGY

Industry	Process source	Control measure				
			Capture/collection			
		Wet suppression[a]	Enclosures[b]	Receiving hoods[c]	Capture hoods	Plume after-treatment
Iron and Steel Plants	Coal Crushing/Screening	X		X	X	X
	Coke Ovens			X		
	Coke Oven Pushing		X	X	X	
	Sinter Machine Windbox	X	X	X		
	Sinter Machine Discharge		X	X	X	
	Sinter Cooler		X			
	Blast Furnace Charging					
	Blast Furnace Tapping		X	X		
	Slag Crushing/Screening	X			X	X
	Molten Iron Transfer			X		
	BOF Charging/Tapping/Leaks		X	X		
	Open Hearth Charging/Tapping/Leaks		X	X		
	EAF Charging/Tapping/Leaks		X	X	X	
	Ingot Pouring			X		
	Continuous Casting			X		
	Scarfing		X		X	
Ferrous Foundries	Furnace Charging/Tapping		X	X		
	Ductile Iron Inoculation		X	X		
	Pouring of Molten Metal			X		
	Casting Shakeout		X	X		
	Cooling/Cleaning/Finishing of Castings			X		
	Core Sand and Binder Mixing				X	
	Core Baking			X		
Primary Aluminum Production	Grinding/Screening/Mixing/ Paste Production		X			
	Anode Baking			X		
	Electrolytic Reduction Cell		X	X	X	
	Refining and Casting		X	X	X	
Primary Copper Smelters	Roaster Charging		X	X		
	Roaster Leaks		X			
	Furnace Charging/Tapping/ Leaks		X	X		
Primary Copper Smelters	Slag Tapping/Handling		X	X		
	Converter Charging/Leaks			X		
	Blister Copper Tapping/Transfer		X	X		
	Copper Tapping/Casting		X	X		

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[a] Water or water plus chemical additives.

[b] Includes full and/or partial enclosures with possible evacuation to a dust collector.

[c] Most applications involve the use of canopy-type receiving hoods.

TABLE 4-2. (continued)

		Control measure				
			Capture/collection			
Industry	Process source	Wet suppression[a]	Enclosures[b]	Receiving hoods[c]	Capture hoods	Plume after-treatment
Primary Lead Smelters	Raw Material Mixing/Pelletizing		X			X
	Sinter Machine Leaks		X	X		
	Sinter Return Handling		X			X
	Sinter Machine Discharge/Screens		X	X		
	Sinter Crushing		X		X	X
	Blast Furnace Charging/Tapping			X		
	Lead and Slag Pouring			X		
	Slag Cooling		X	X		
	Slag Granulator	X	X			
	Zinc Fuming Furnace Vents		X			
	Dross Kettle			X		
	Silver Retort Building		X			
	Lead Casting			X		
Primary Zinc Production	Sinter Machine Windbox Discharge		X	X		
	Sinter Machine Discharge/Screens		X	X		
	Coke-Sinter Mixer		X		X	
	Furnace Tapping		X	X		
	Zinc Casting			X		
Secondary Aluminum Smelters	Sweating Furnace			X		
	Smelting Furnace Charging/Tapping		X	X		
	Fluxing			X	X	
	Dross Handling and Cooling		X	X		
Secondary Lead Smelters	Scrap Burning					
	Sweating Furnace Charging/Tapping		X	X		
	Reverb Furnace Charging/Tapping		X	X		
	Blast Furnace Charging/Tapping		X	X		
	Pot Furnace Charging/Tapping		X	X		
	Tapping of Holding Pot		X	X		
	Casting		X	X		
Secondary Zinc Production	Sweating Furnace Charging/Tapping		X	X		
	Hot Metal Transfer		X			
	Melting Furnace Charging/Tapping		X	X		
	Distillation Retort Charging/Tapping		X	X		
	Distillation Furnace Charging/Tapping		X	X		
	Casting		X	X		

[a] Water or water plus chemical additives.

[b] Includes full and/or partial enclosures with possible evacuation to a dust collector.

[c] Most applications involve the use of canopy-type receiving hoods.

TABLE 4-2. (concluded)

Industry	Process source	Control measure				
		Wet suppression[a]	Capture/collection			
			Enclosures[b]	Receiving hoods[c]	Capture hoods	Plume after-treatment
Secondary Copper, Brass/Bronze Production	Sweating Furnace Charging/Tapping		X	X		
	Dryer Charging/Tapping		X	X		
	Melting Furnace Charging		X	X		
	Casting		X	X		
Ferroalloy Production	Raw Materials Crushing/Screening	X	X		X	X
	Furnace Charging		X	X	X	
	Furnace Tapping		X	X	X	
	Casting		X	X	X	
Cement Manufacturing	Limestone/Gypsum Crushing and Screening	X	X		X	X
	Coal Grinding	X	X		X	X
Lime Manufacturing	Limestone Crushing/Screening	X	X		X	X
	Lime Screening/Conveying		X		X	X
Rock Products	Primary Crushing/Screening	X	X		X	X
	Secondary Crushing/Screening	X	X		X	X
	Tertiary Crushing Screening	X	X		X	X
Asphalt Concrete Plants	Aggregate Crushing/Screening	X	X		X	X
Coal-Fired Power Plants	Coal Pulverizing/Screening	X	X		X	
Grain Storage and Processing	Grain Cleaning				X	
	Grain Drying				X	
Wood Products	Log Debarking/Sawing		X		X	X
	Veneer Drying		X	X		
	Plywood Cutting		X		X	X
	Plywood Sanding		X		X	X
Mining	Blasting	X				
	Crushing/Screening	X	X		X	X

---

[a] Water or water plus chemical additives.

[b] Includes full and/or partial enclosures with possible evacuation to a dust collector.

[c] Most applications involve the use of canopy-type receiving hoods.

At the other extreme, a control efficiency value based only on estimation is assigned an E rating.

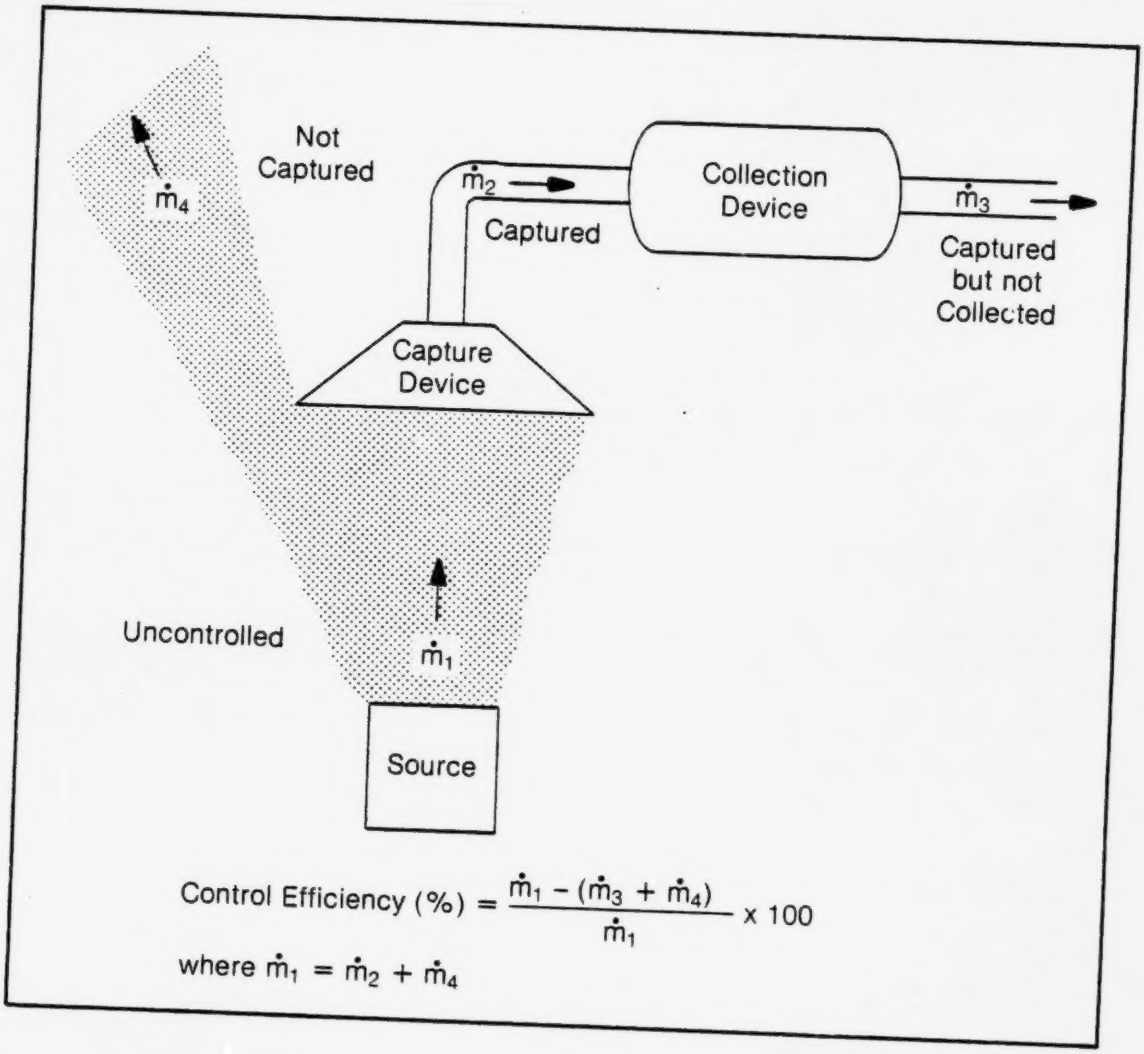
In the case of a capture/collection system applied to a process source of fugitive emissions, the controlled emissions are made of: (a) that portion of the uncontrolled emissions which are not captured, plus (b) that portion of the uncontrolled emissions which are captured but not collected. This is illustrated in Figure 4-8 for a canopy hood. Frequently testing is performed at the inlet and outlet of the collection device, but the data are insufficient to determine the overall control efficiency.

With regard to sufficiency in the number of tests required to reliably quantify the average emission rate (controlled or uncontrolled) at a sampling location, this depends on the variability of the emission rate. Traditionally, three tests of a process source represent the minimum requirement for reliable quantification.

For preventive control measures and plume aftertreatment, either of two study designs may be used to determine the control efficiency. A Type 1 design entails the measurement of source emissions with and without the application of control. In a Type 2 design, emissions from identical sources are measured, one with control and other without control. It must be shown that the two sources are identical in terms of their uncontrolled emissions.

The question of the representativeness of the source operation and control system being tested is germane only if a widely applicable control efficiency value is being sought. In such a case, the value should be based on tests of several source/control facilities of the same type which typify a particular industry. However, unless the variability of the determined control efficiency values from one facility to another is small, it is preferable to list each value separately with the corresponding source/control parameters. This procedure opens the possibility of developing a statistical performance model which mathematically relates the observed variance in control efficiency to the variances in the source/control parameters.

In Chapters 5 and 6, the following protocol is used for presenting published control efficiency values (in tabular form):


Not Captured
$\dot{m}_4$
$\dot{m}_2$
Captured
Collection Device
$\dot{m}_3$
Captured but not Collected
Capture Device
Uncontrolled
$\dot{m}_1$
Source

$$\text{Control Efficiency (\%)} = \frac{\dot{m}_1 - (\dot{m}_3 + \dot{m}_4)}{\dot{m}_1} \times 100$$

where $\dot{m}_1 = \dot{m}_2 + \dot{m}_4$

Figure 4-8. Emissions quantification requirements for performance evaluation of capture/collection system

1. For a given source and control system combination, each control efficiency value is presented with a reliability rating (A through E) based on the degree to which the value was determined from a sound, adequately documented testing program.

2. To properly define the representativeness (applicability) of a control efficiency value, the distinguishing source emission and control system parameters are specified with the efficiency value. The reader is cautioned that the reliability rating must be reduced if the control efficiency value is applied to a source/control combination in the same category but with one or more parameters which differ significantly from those specified. More than one control efficiency value are presented for the same generic source/control combination, if the specified source/control parameters are not equivalent for the available efficiency values.

3. Each control efficiency value is referenced to the original source of test data or rationale for an estimate. This approach eliminates the confusion which results from referencing more recent documents that may (or may not) reference the original source of the control efficiency value. As a general rule, values which cannot be traced to an original reference documents that are accessible to the public, are not listed.

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SECTION 5

ESTIMATION OF CONTROL SYSTEM PERFORMANCE — OPEN SOURCES

The performance capability of an open dust source control system depends on a variety of parameters related to (a) properties of the emitting material, (b) characteristics of the equipment involved in the source operation, (c) climatic factors, and (d) the "intensity" of control application. Furthermore, because of site-to-site differences in most of these parameters, the performance of a given control system can be expected to vary significantly from one application to another. Therefore, in utilizing the control efficiency data presented in this section for control performance assessment, care must be taken to document the source and control parameters tied to each control efficiency data set.

The alternative approaches available for the control of open dust sources include:

1. Stabilization of Unpaved Travel Surfaces

    - Wet suppression
    - Chemical stabilization
    - Physical stabilization
    - Paving

2. Improvement of Paved Travel Surfaces

    - Surface cleaning
    - Resurfacing
    - Reduction of track-on

3. Stabilization of Piles/Exposed Areas

    - Wet suppression
    - Chemical stabilization
    - Physical stabilization

4. Enclosure of Piles/Exposed Areas or Materials Handling
   - Passive enclosures (including wind fences)
   - Active enclosures
5. Wet Suppression for Materials Handling
6. Plume Aftertreatment for Materials Handling
   - Fine water sprays
   - Charged fog

The first three of these categories and passive enclosures are preventive measures, whereas active enclosures and plume aftertreatment are capture/removal methods.

Most of the preventive measures involve periodic rather than continuous control application. Familiar examples are the watering of unpaved travel surfaces and the cleaning of paved travel surfaces. The resultant control efficiency follows a cyclic pattern, decaying in time from the highest value immediately after application. Because of the finite durability of these control techniques, ranging from hours to months, it is essential to relate an average efficiency value to a frequency of application. For measures of extended durability such as paving, the application program required to sustain control effectiveness should be indicated. One likely pitfall to be avoided is the use of field data collected soon after control measure application to represent the average control efficiency over the lifetime of the measure.

For a periodically applied control measure, the most representative value of control efficiency is the time average, given by:

$$C(T) = \frac{1}{T} \int_0^T c(t)\, dt \qquad (5\text{-}1)$$

where:

$C(T)$ = average control efficiency during period of T days between application (percent)

$c(t)$ = instantaneous control efficiency at t days after application (percent), where $t \leq T$

It must be emphasized that the rate of control efficiency decay is heavily dependent upon the source and control variables discussed in the following sections.

5.1 STABILIZATION OF UNPAVED TRAVEL SURFACES

5.1.1 Design Considerations

Control efficiency values for unpaved road dust controls can be affected by four categories of variables: (a) control application parameters; (b) vehicle characteristics; (c) properties of the surface to be treated; and (d) climatic factors. Each of these categories will be discussed in the following paragraphs.

The control application parameters affecting control performance of chemical dust suppressants are: (a) application intensity; (b) application frequency; (c) dilution ratio; and (d) application procedure. Application intensity is the volume of diluted solution placed on the surface per unit area of surface (e.g., L/m^2 or gal/yd^2). The higher the intensity, the higher the anticipated control efficiency. However, this relationship applies only to a point, because too intense an application will begin to run off the surface. The point where runoff occurs depends on the slope and porosity of the surface. Application frequency is the number of applications per unit of time. The dilution ratio is the volume of chemical concentrate divided by the volume of water (e.g., 1:7 dilution ratio = 1 part chemical to 7 parts water).

The decay in control efficiency of a chemical dust suppressant occurs largely because vehicles traveling over the road surface impart energy to the treated surface which breaks the adhesive bonds that keep fine particles on the surface from becoming airborne. Figure 5-1 is a general plot portraying the change in rate of decay of the instantaneous control efficiency for a chemical suppressant applied to an unpaved road as a function of vehicle speed, weight, and traffic rate. As indicated, an increase in vehicle weight and speed serves to accelerate the decay in efficiency for chemical treatment of unpaved roads.

Any surface characteristics which contribute to the breaking of a surface crust will adversely affect the control efficiency. For example, the

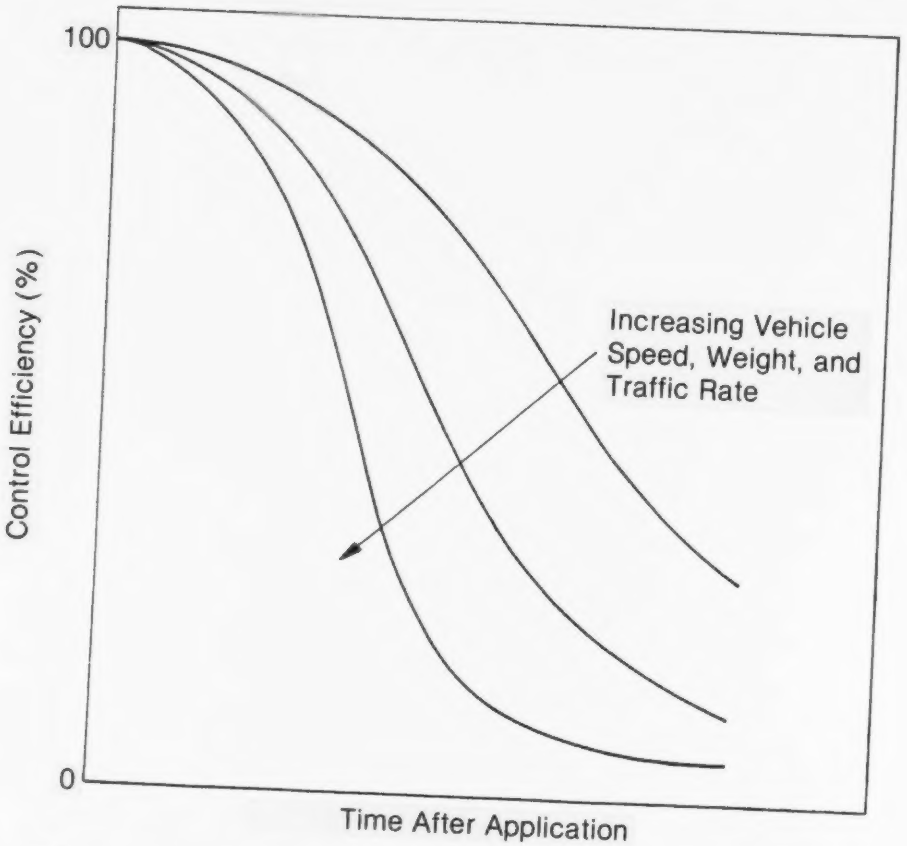

Figure 5-1. Effect of vehicle speed, weight, and traffic rate on control performance

structural characteristics of an unpaved road affect the performance of chemical controls. These characteristics are: (a) combined subgrade and base bearing strength, as measured by the California Bearing Ratio (CBR); (b) amount of fine material (silt and clay) on the surface of the road; and (c) the friability of the road surface material. Low bearing strength causes the road to flex and rut in spots with the passage of heavy trucks; this destroys the compacted surface enhanced by the chemical treatment. A minimum amount of fine material in the wearing surface is needed to provide the chemical binder with the particle surface area necessary for effective interparticle bonding. Finally, the larger particles of a friable wearing surface material simply break up under the weight of the vehicles and cover the treated road with a layer of untreated dust.

For the most part, adverse weather, accelerates the decay of control performance. For example, freeze-thaw cycles break up the crust formed by chemical binding agents; heavy precipitation washes away water-soluble chemical treatments like lignin sulfonates; and intense solar radiation dries out watered surfaces. On the other hand, light precipitation might improve the efficiency of water extenders and hygroscopic chemicals like calcium chloride.

5.1.2 **Performance Data**

The control of dust emissions from unpaved roads has received the widest attention in the literature (see Table 5-1). Exposure profiling and upwind/downwind sampling have been used to measure control efficiencies for watering

TABLE 5-1. CLASSIFICATION OF TESTED ROAD DUST SUPPRESSANTS

Dust suppressant category	Trade name	Number of valid controlled tests	Reference numbers
Petroleum-based	Petro Tac	8	1-3,
	Coherex	124	1-6
	Arcote 220	4[a]	4
	Arco 2200	20	8
	Arco 2400	91	7
Lignosulfonates	Lignosite	73	7
	Trex	3	10
	Flambinder	4[a] + 28	4
Salts	Peladow	1	9
	Liquidow	34	8
	Dustgard	11 (17)[b]	7
	Oil Well Brine	4	4
Polymer	Soil Sement	24	8
Surfactant	Biocat	3	8

[a] Arcote 220/Flambinder mixture.

[b] Numbers without parentheses represent TSP and numbers in parentheses represent respirable particulate.

and for a range of chemicals which bind the surface material or increase its capacity for moisture retention. Tables 5-2 and 5-3 summarize the measured performance data for chemical dust suppressants.

The observed control efficiency decay functions for several dust suppressants, are shown in Figures 5-2 to 5-9. These functions are properly expressed in terms of vehicle passes rather than time because vehicle traffic is the primary cause of the loss of control effectiveness. The control efficiency decay functions can be used to derive the critical relationships between average control efficiency and application frequency. Assuming, as a first approximation, that control efficiency decays linearly from an initial value of 100%, the average control efficiency for a given frequency of application is the mean of 100% and the value at the end of the decay cycle.

The quality rating of control performance data for a periodically applied control measure must address the reliability of the average control efficiency for the particular application frequency tested. Obviously, a spread in the measured values of instantaneous control efficiency is expected, as the efficiency decays. Rather the quality rating must be based on how well the instantaneous values fit a decay function. At the time of this writing, mathematically derived decay functions were available for only a few of the control measures. Therefore, no quality ratings were assigned to the control efficiency data presented.

Most of the studies identified in Tables 5-2 and 5-3 were performed on roads in iron and steel plants or surface coal mines, using both Type 1 and Type 2 study designs (as defined in Section 4.4). Because of differences in the dust suppressants, application parameters and traffic conditions from one study site to another, there is little overlap in the applicability of the published control efficiency values.

In most of the extended tests of control performance, efficiency values were found to decay with vehicle passes (and time) after application. In Figures 5-2 through 5-4, the best-fit linear decay functions determined by least-squares analysis are shown. In Figures 5-5 through 5-9, the data points are connected by line segments.

TABLE 5-2. SUMMARY OF MAJOR UNPAVED ROAD DUST SUPPRESSANT CONTROL EFFICIENCY TESTS

Ref. No.	Dust suppressant tested	No. of valid controlled tests	Test site	Measurement method[a]	Time after application (days)	Application intensity (gal. sol./yd²)	Dilution ratio (gal. chem: gal. H_2O)	Avg. vehicle weight (ST)	Control efficiency[b] (%)
1-3	Coherex®	2	Steel plant	P	< 7	Unknown	1:9	3	91[c]
	Coherex®	4	Steel plant	P	1-2	0.19	1:6	50	TP 92-98 TSP 91-96 FP 90-97
	Coherex®	5	Steel plant	P	1-2	0.19	1:6	3	TP 94-100 TSP 91-99 FP 92-97
5-6	Coherex®	4	Steel plant	P	Unknown	Unknown	Unknown	4-19	TP 81
	Coherex®	2	Steel plant	P	14-15	Unknown[d]	1:4-1:7	26	TP 99
7	Coherex®	91	Public road	U/D	30-270	1.5[e] 0.33[f]	1:5[e] 1:9[f]	4	TSP 53 RP 64
	Arco 2400	91	Public road	U/D	30-270	3.5	1:0	4	TSP 96 RP 57
	Lignosite (50% solids)	73	Public road	U/D	30-270	0.125[e] 0.25[f]	1:1[e] 1:1[f]	4	TSP 46 RP 42
	Dustgard	11 (17)[e]	Public road	U/D	3-60	0.5	1:0[g]	4	TSP 48 RP 24
	Peladow	1	Surface coal mine	P	90	0.6	1:2	3	TSP 95 RP 95 FP 88
10	Trex (ammonium lignin sulfonate)	3	Taconite mine	P	< 7	0.08	1:4	110-127	TSP 88

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[a] P = profiling; U/D = upwind/downwind.

[b] TP = total particulate; TSP = total suspended particulate; RP = respirable particulate; FP = fine particulate

[c] Particles of less than 30 μm stokes diameter (47 μm aerodynamic diameter).

[d] Four applications were put down with testing beginning 2 weeks after fourth application.

[e] Initial application.

[f] Repeat application.

[g] Not diluted further; however, dilution as shipped not specified.

TABLE 5-3. SUMMARY OF MAJOR UNPAVED ROAD DUST SUPPRESSANT CONTROL EFFICIENCY DECAY FUNCTION TESTS

Ref. No.	Dust suppressant tested	No. of valid controlled tests	Test site	Measurement method[a]	Time after application (days)	Application intensity (gal. sol./yd²)	Dilution ratio (gal. chem: gal. H_2O)	Avg. vehicle weight (ST)	Efficiency decay function (Fig.)
1-3	Petro Tac	8	Steel plant	P	2-116	0.70	1:4	23-34	5-2
	Coherex®	8	Steel plant	P	7-41	0.83[b]	1:4[b]	27-50	5-3
	Coherex®	4	Steel plant	P	4-35	1.0[c,d]	1:8[c,d]	31-56	5-4
4	Coherex®	5	Steel plant	U/D	17-35	1.5	1:4	3	5-5
	Oil well brine	5	Steel plant	U/D	17-35	3.8	Neat	3	5-5
	Arcote 220 and Flambinder	5	Steel plant	U/D	17-35	1.9	1:4	3	5-5
8	LiquiDow	8	Surface coal mine 1	P	14-49	0.27-0.6	1:1.6	28-66[e]	5-6
		18	Surface coal mine 2	P	7-28	0.27-0.6	1:1.6	44-83[e]	5-6
		8	Surface coal mine 3	P	14-21	0.3-0.6	1:1.9	70-27[e]	5-6
	Soil Sement	12	Surface coal mine 1	P	21-42	1.9-3.0	1:8.3	22-89[e]	5-7
		12	Surface coal mine 2	P	7-35	1.0	1:6.4	38-82[e]	5-7
	Biocat	3	Surface coal mine 3	P	7-14	2.0	1:20,000	70-276[e]	5-7
	Flambinder	4	Surface coal mine 1	P	14	0.5-2.1	1:4.6	16-65[e]	5-8
		16	Surface coal mine 2	P	7-28	0.5-2.0	1:4.6	51-69[e]	5-8
		8	Surface coal mine 3	P	7-21	1.8	1:4.6	70-276[e]	5-8
	Arco 2200	16	Surface coal mine 2	P	7-28	0.9-2.8	1:7	18-80[e]	5-9
		4	Surface coal mine 3	P	7	1.1-2.3	1:6.1	70-276[e]	5-9

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[a] P = profiling; U/D = upwind/downwind.

[b] Initial application.

[c] Repeat application.

[d] The main test section of the road was retreated 44 days after the initial application.

[e] Values represent range of haul truck weights from empty to loaded vehicles. Haul truck has 10 wheels at mines 1 and 2 and six wheels at mine 3.

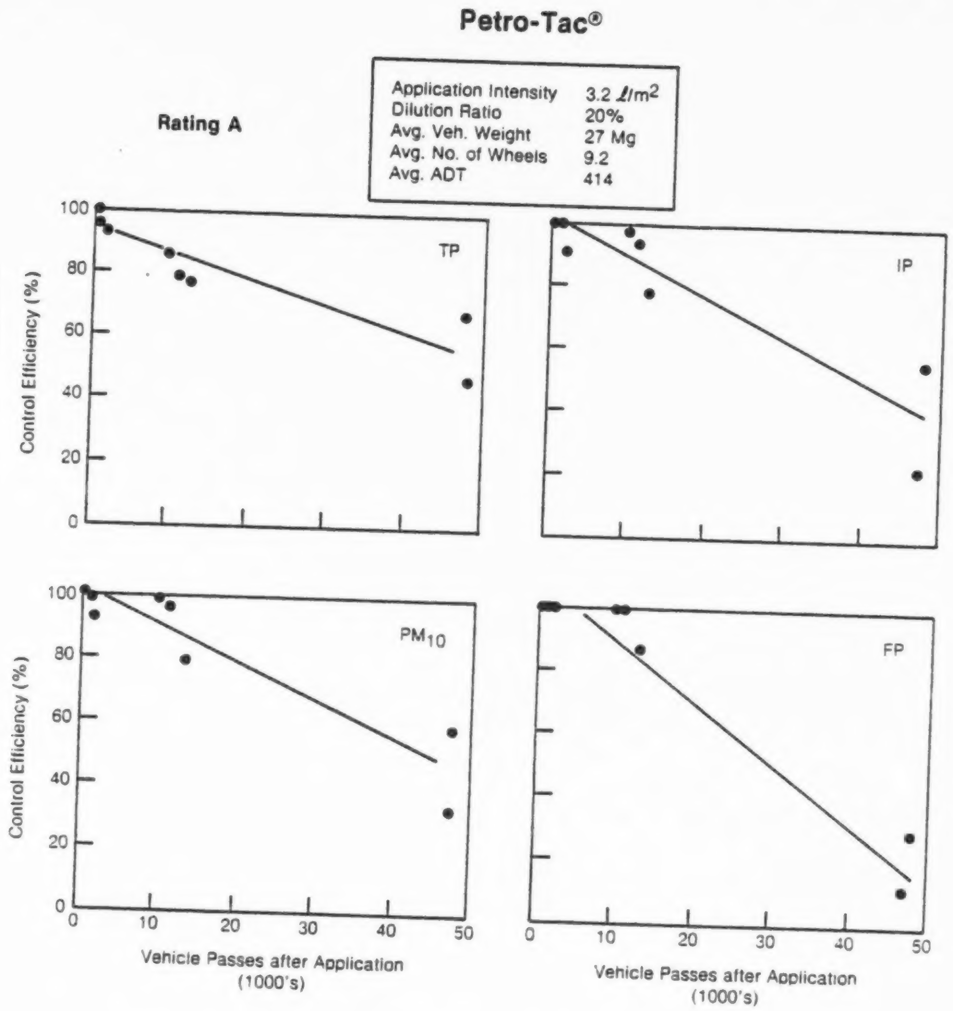


Figure 5-2. Control efficiency decay for an initial application of Petro Tac®[1-3]

Coherex®

Rating B

Application Intensity	3.8 ℓ/m^2
Dilution Ratio	20%
Avg. Veh. Weight	34 Mg
Avg. No. of Wheels	6.2
Avg. ADT	95

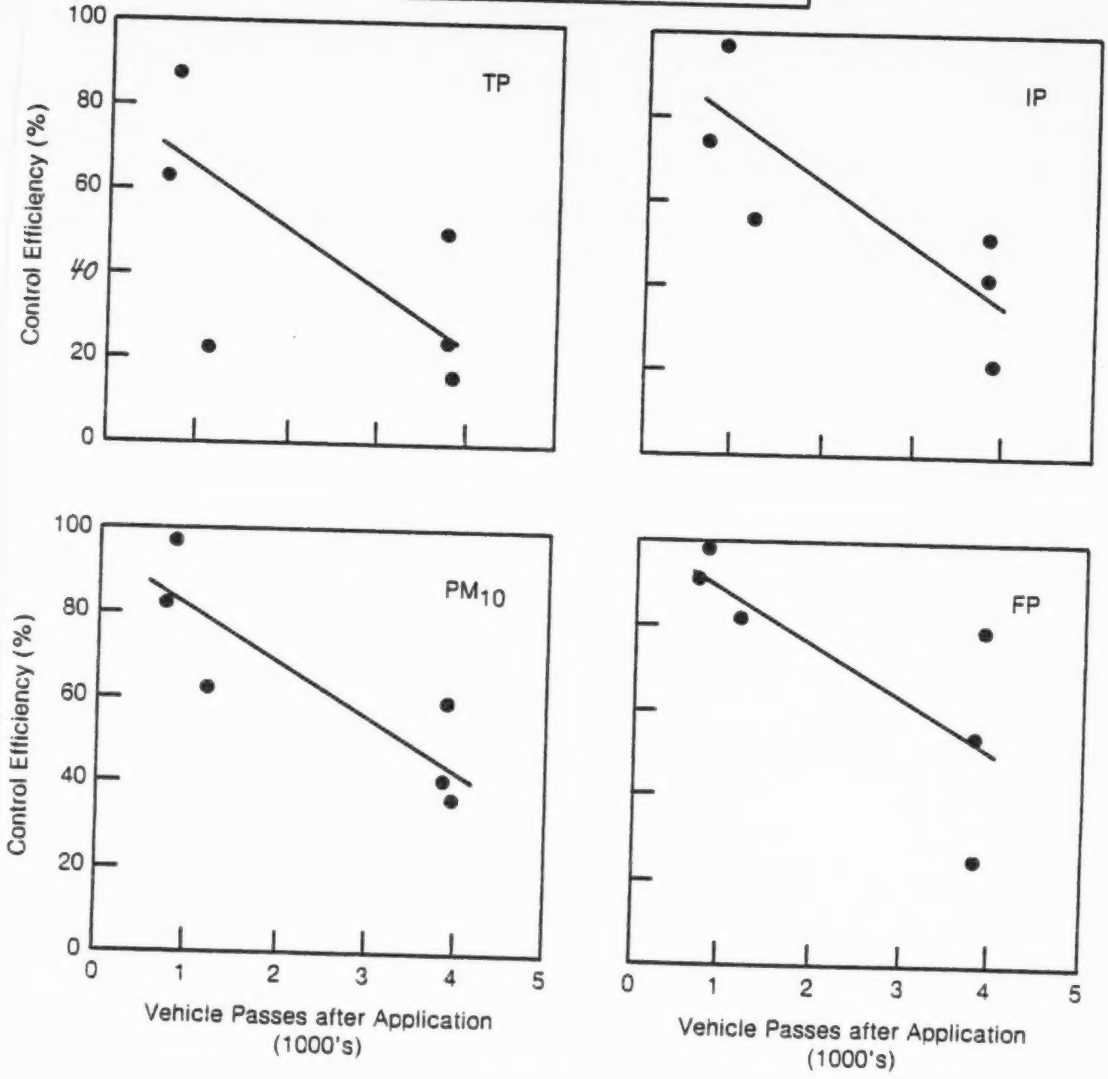


Figure 5-3. Control efficiency decay for an initial application of Coherex®[1-3]

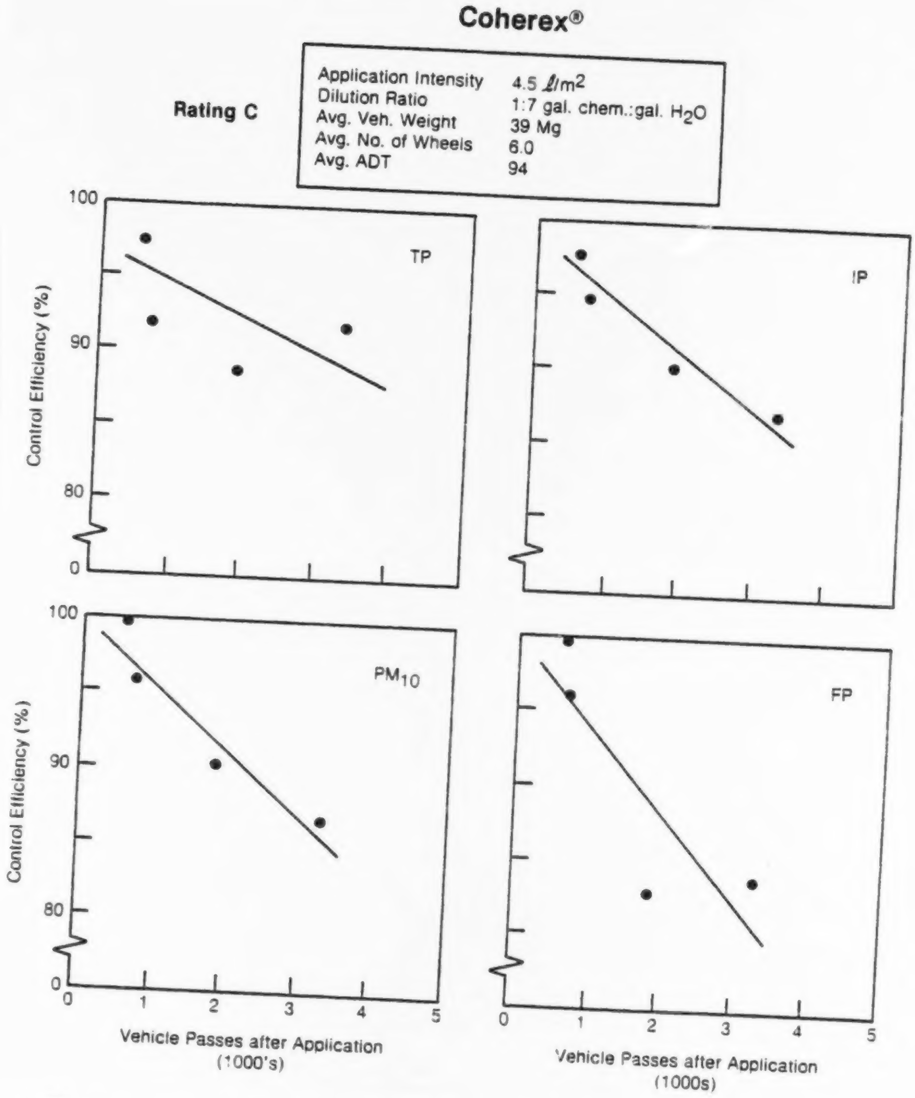


Figure 5-4. Control efficiency decay for a reapplication of Coherex®[1-3]

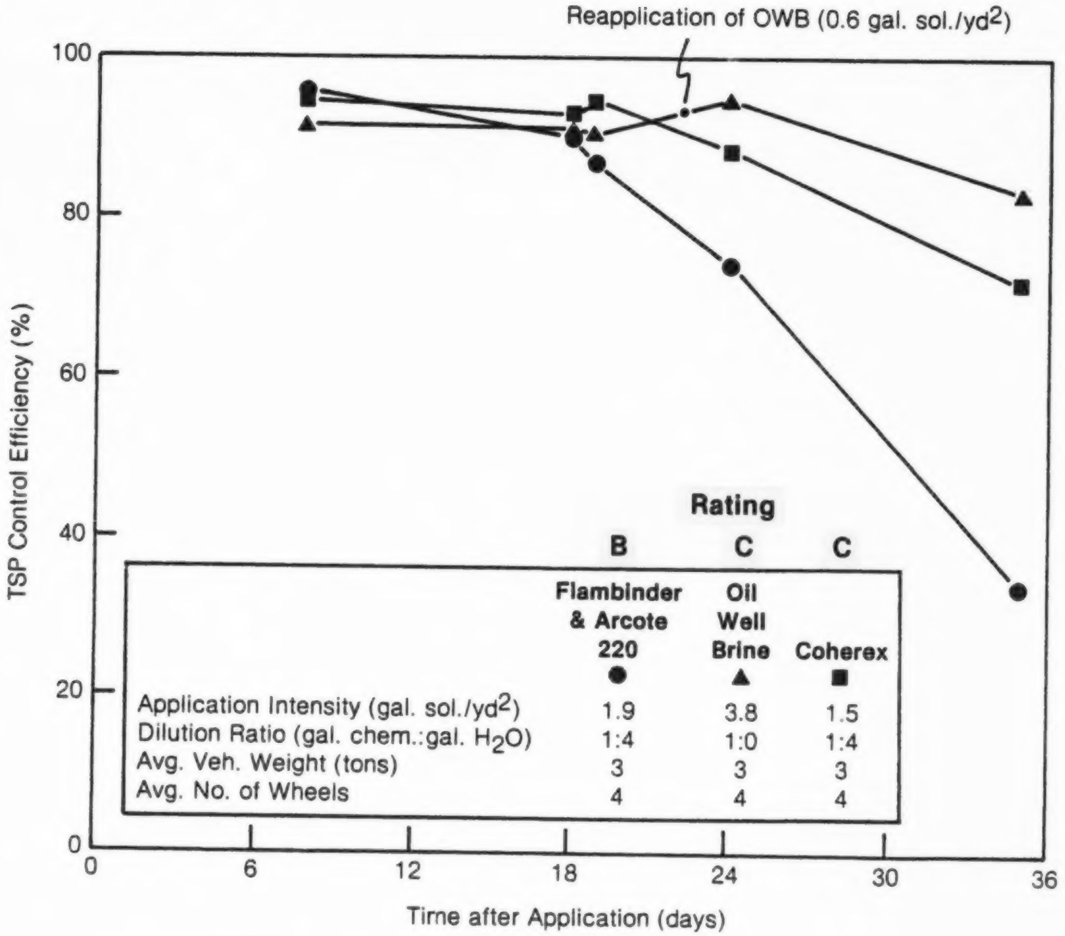


Figure 5-5. TSP control efficiency decay for light-duty traffic on unpaved roads[4]

LiquiDow®

Mine	1 ———	2 —·—·—	3 •••••••••
Application Intensity (gal. sol./yd^2)	0.27-0.6	0.27-0.6	0.3-0.6
Dilution Ratio (gal. chem.:gal. H_2O)	1:1.6	1:1.6	1:1.9
Avg. Veh. Weight (tons)	28-66	44-83	70-276
Avg. No. of Wheels	10	10	6
Rating	D	D	D

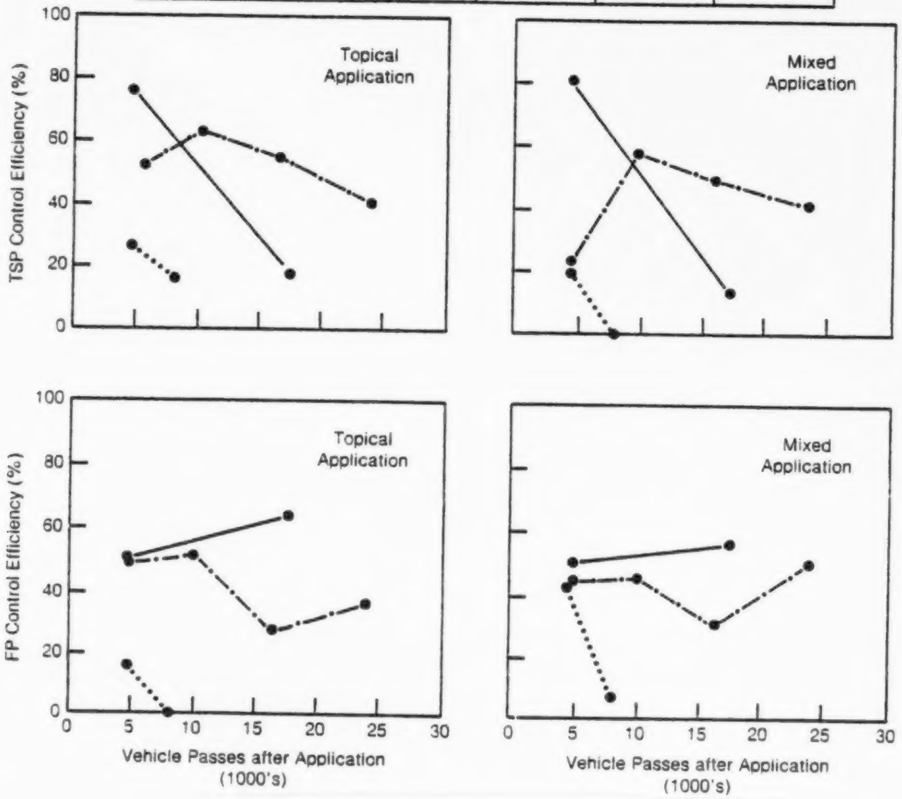


Figure 5-6. Decay of control efficiency for LiquiDow® applied to haul roads[8]

	Soil Sement®		**Biocat-Enzyme®**
Mine	1 ———	2 -·-·-	3 ·········
Application Intensity (gal. sol./yd²)	1.9-3.0	1.0	2.0
Dilution Ratio (gal. chem.:gal. H_2O)	1:8.3	1:6.4	1:20,000
Avg. Veh. Weight (tons)	22-89	38-82	70-276
Avg. No. of Wheels	10	10	6
Rating	B	B	D

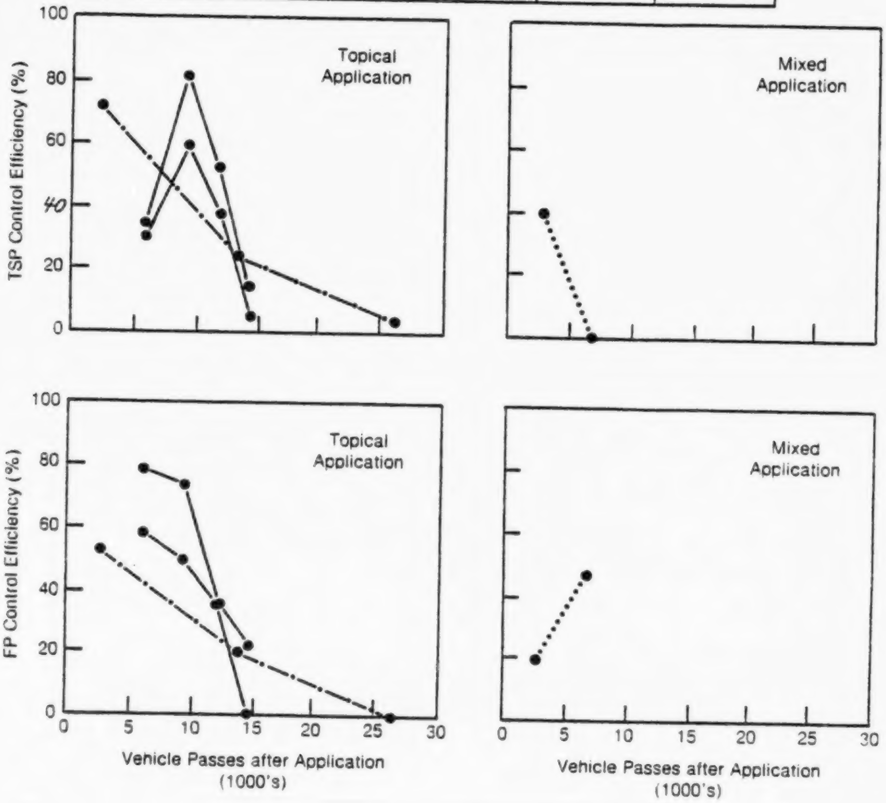
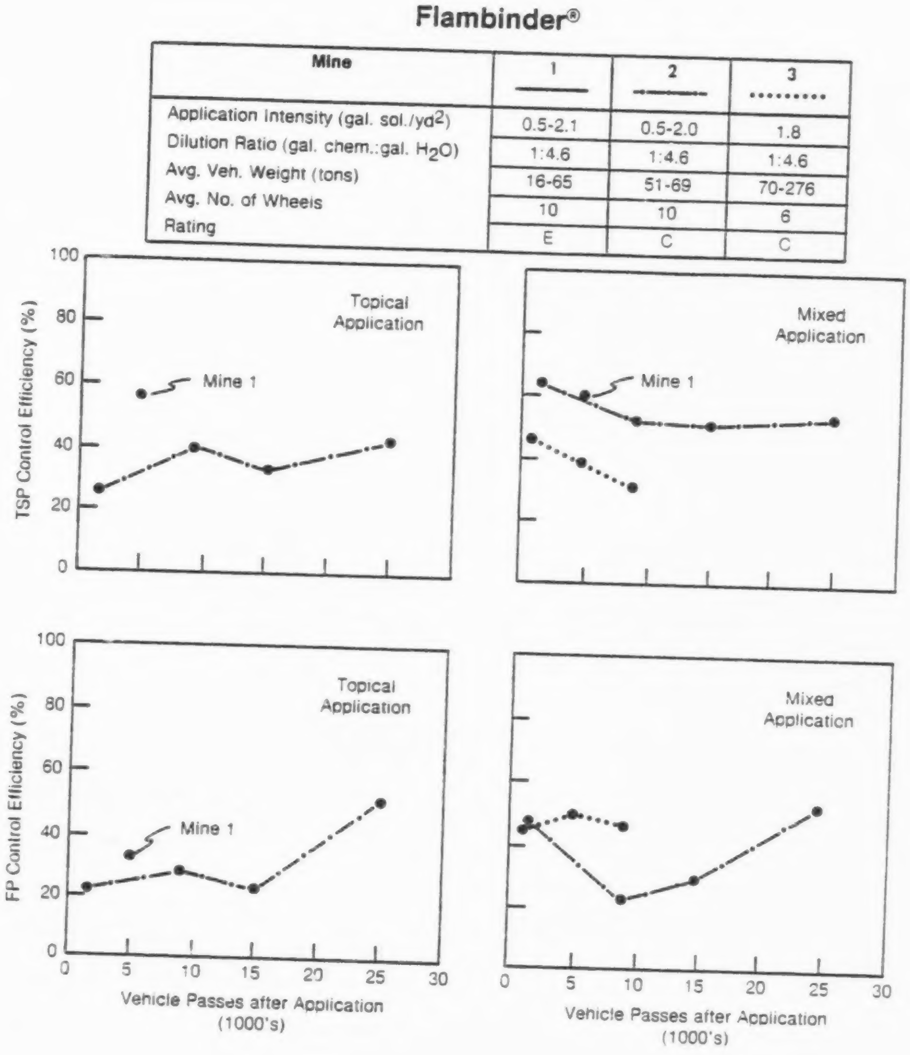


Figure 5-7. Decay of control efficiency for Soil Sement® and Biocat-Enzyme® applied to haul roads[8]



Flambinder®

Mine	1 ———	2 -·-·-·-	3 ·········
Application Intensity (gal. sol./yd^2)	0.5-2.1	0.5-2.0	1.8
Dilution Ratio (gal. chem.:gal. H_2O)	1:4.6	1:4.6	1:4.6
Avg. Veh. Weight (tons)	16-65	51-69	70-276
Avg. No. of Wheels	10	10	6
Rating	E	C	C

Figure 5-8. Decay of control efficiency for Flambinder® applied to haul roads[8]

Arco 2200®

Mine	2 -·-·-·-	3 ·········
Application Intensity (gal. sol./yd.^{2})	0.9-2.8	1.1-2.3
Dilution Ratio (gal. chem.:gal. H_2O)	1:7	1:6.1
Avg. Veh. Weight (tons)	18-80	70-276
Avg. No. of Wheels	10	6
Rating	C	E

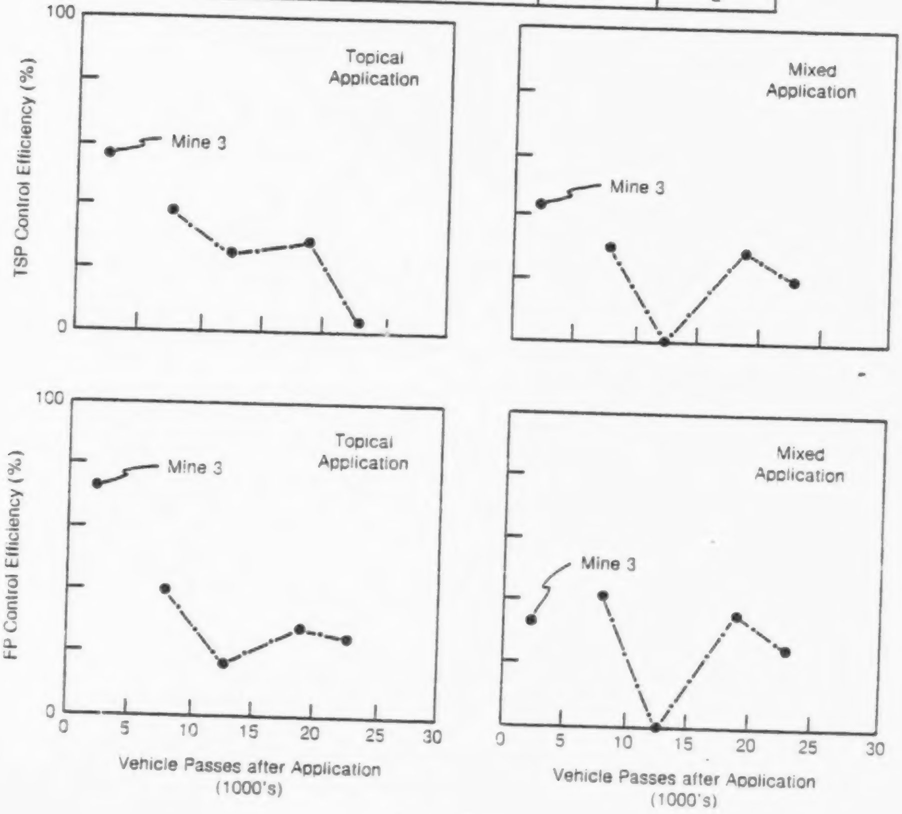


Figure 5-9. Decay of control efficiency for Arco 2200® applied to haul roads[8]

Apparent increases in control efficiency with vehicle passes were observed in several test series from Reference 8. This anomalous behavior is thought to be the result of moisture effects on the uncontrolled emission rate, which was measured simultaneously with each controlled emission rate. In other words the efficiency values were not always referenced to a dry uncontrolled emission rate.

An empirical model for the performance of a watering as a control technique has been developed.[11] The supporting data base consists of 14 tests performed in four states during five different summer and fall months.[1-3] The model is:

$$C = 100 - \frac{0.8\ p\ d\ t}{i} \tag{5-2}$$

where:

C = average control efficiency (percent)

P = potential average hourly daytime evaporation rate (mm/hr)

d = average hourly daytime traffic rate (hr^{-1})

i = application intensity (L/m^2)

t = time between applications (hr)

The data to support this empirically based mathematical model are shown in Table 5-4. No significant difference in the average control efficiency of

TABLE 5-4. FIELD DATA ON WATERING CONTROL EFFICIENCY[1-3]

Location	No. of tests	Month	Applic. intens. (L/m^2)	Avg. time between applic. (hr)	Avg. traf. rate (hr^{-1})	Avg. poten. evap. (mm/hr)	Avg. control eff.[a] (%)
N. Dakota	4	October	0.2	1.8	40	0.084	59
New Mexico	5	July/Aug.	0.2	2.0	23	0.23	69
Ohio	3	November	0.6	4.5	98	0.042	77
Missouri	2	September	1.9	2.8	72	0.26	88

[a] No significant difference in control efficiency as a function of particle size was observed.

watering as a function of particle size has been established to date. As with all empirical models, Eq. 5-2 should not be applied beyond the ranges of independent variable values tested.

The control efficiencies afforded by paving of unpaved road segments can be estimated by comparing the AP-42 emission factors for the unpaved and paved road conditions. The emission factor for the paved road condition requires an estimated silt loading on the paved surface. An urban street dust loading model[12] can be used to estimate silt loadings as a function of traffic volume. The model is expressed as follows:

$$sL = 21.3\ (ADT)^{-0.41} \tag{5-3}$$

where:

sL = silt loading (g/m^2)

ADT = average daily traffic (vehicles/day)

This urban model was developed from silt loading measurements in five urban areas (Baltimore, Buffalo, Granite City (IL), Kansas City, and St. Louis). All of the streets were paved edge to edge and had curbs and gutters. The calculated control efficiencies for paving are usually of the order of 90%.

The results of additional field testing of haul road watering are presented in Table 5-5.

5.2 IMPROVEMENT OF PAVED TRAVEL SURFACES

5.2.1 Design Considerations

Resuspended dust emissions from vehicles traveling on paved roads can be controlled by removing the dust from the road surface. Techniques for removing dust from paved roads include broom sweeping, vacuum sweeping, flushing, and a combination of flushing and broom sweeping. The control efficiency afforded by any of these road cleaning techniques decays with time and with vehicle passes after cleaning. This is due to the buildup of dust on the surface because of track-on from unpaved surfaces, release of vehicle underbody catch debris, atmospheric deposition, and rainstorm wash-on.

TABLE 5-5. COMPOSITE CONTROL EFFECTIVENESS OF WATERING[8]

	Period between applications (min)		
	120	60	30
Mine 1			
Control eff. (%)			
TSP	16	37	51
FP	29	40	43
Vehicles/hr	32	24	28
Mine 2			
Control eff. (%)			
TSP		41	59
FP		26	47
Vehicles/hr		65	78

The control efficiency achieved by vacuuming is influenced by many variables such as:

1. Blower capacity in ACFM.
2. The air velocity generated along the road surface.
3. The condition of the road surface (small particles can be shielded from capture if they rest in holes characteristic of a rough, poor quality surface).
4. Characteristics of the gutter broom (e.g., rpm, type of bristle, number of bristles per unit area).
5. Type of device used to remove particles (e.g., bags, water sprays, scrubbers, etc.).

5.2.2 Performance Data

In contrast to controls for unpaved roads, few published values are available for control measures applicable to paved roads. A limited number of exposure profiling tests have been performed to measure the control efficiency achieved by vacuum sweeping, water flushing, and water flushing followed by broom sweeping of steel plant paved roads.[1] Also, the efficiency of an improved vacuum sweeper has been determined indirectly by quantifying the reduction in surface loading on two city streets.[13]

Tables 5-6 and 5-7 list the available control efficiency data for each of the four road cleaning techniques mentioned above. In Table 5-6, the control efficiencies of vacuuming are listed as single values measured at specific times after application. In Table 5-7, the control efficiencies of the remaining techniques are quantified as a function of vehicle passes after application. All the data in Tables 5-6 and 5-7 are based on field testing using the exposure profiling method.

The broom sweeper control efficiency data from Table 5-7 indicate that the highest control efficiency achievable by broom sweeping alone is 27% immediately after application. The data suggest that daily broom sweeping would achieve approximately 25% control. The principles behind the effectiveness of broom sweeping suggest that broom sweeping alone cannot be improved enough to capture an adequate amount of fine particulate.

The flusher control efficiency data suggest that flushing at a rate of 0.48 gal/yard^2 can produce a maximum of 69% control immediately after application and that it will decay to zero after 300 vehicle passes. The equation presented in Table 5-7 was based on tests conducted at a steel plant in Houston, Texas. The average vehicle weight during testing was 10 tons, and the road was completely surrounded by unpaved areas accessible to vehicles. The control efficiency equation in Table 5-7 shows that water flushing and broom sweeping together are more effective than either technique used separately.

Emissions of traffic-entrained road dust can also be reduced by resurfacing of paved roads that have deteriorated resulting in increased surface dust loadings. The control efficiency resulting from resurfacing of a paved

TABLE 5-6. MEASURED SINGLE-VALUED PARTICULATE CONTROL EFFICIENCIES FOR VACUUM SWEEPING[1]

Vacuum type	Blower capacity (cfm)	Time after application[a] (hr)	Instantaneous control efficiency (%)	
			TP	IP
Once-through	12,000	2.8	70	51
		24	52	58
		2.1	48	16
		4.1	16	0

[a] As measured to the midpoint of the test.

TABLE 5-7. PARTICULATE CONTROL EFFICIENCY DECAY FUNCTIONS FOR BROOM SWEEPING AND FLUSHING[1]

Control	Application intensity	Average vehicle weight (tons)	Instantaneous control efficiency decay function[a]	
			TP	IP
Water flushing	0.48 gal/yd²	10	66 - 0.130 V	69 - 0.231 V
Water flushing followed by broom sweeping	0.48 gal/yd²	13	90 - 0.294 V	96 - 0.263 V
Broom sweeping[b]	-	12	24 - 0.164 V	27 - 0.032 V

[a] Equation yields control efficiency in percent; V = number of vehicle passes after control is employed.

[b] Control efficiency decay function obtained by difference.

road (application of 2 in. of hot-mix asphalt) may be estimated as equal to the anticipated percentage reduction in silt loading on the travel lanes. This is based on the proportional relationship between emissions and silt loading in the AP-42 emission factor for industrial paved roads.

Curbs are effective in keeping vehicles on the pavement, thereby eliminating tracking from the edge of the pavement. However, other techniques such as painting the road 1 to 2 ft from the edge with a stripe and installing parking caution signs may accomplish this objective at far less expense. Little additional control efficiency is gained by installation of continuous curbing with gutters and sewers unless all adjacent areas (e.g., parking lots and driveways) are also paved. In effect curbs would reduce loadings to that of the urban model (Equation 5-3).

5.3 STABILIZATION OF PILES/EXPOSED AREAS

5.3.1 Design Considerations

Wind erosion of open storage piles and exposed areas is a recognized source of particulate air pollution associated with the mining and processing of metallic and nonmetallic minerals. Preventive methods for control of windblown emissions from raw material storage piles consist of wetting, chemical stabilization, and enclosures. Physical stabilization by covering the exposed surface with less erodible aggregate material and/or vegetative stabilization are seldom practical control methods for raw material storage piles.

5.3.2 Performance Data

To test the effectiveness of controls for wind erosion of storage piles and tailings piles, wind tunnel measurements have been performed. Although most of this work has been carried out in laboratory wind tunnels, portable wind tunnels have been used in the field on storage piles[1] and tailings piles.[14] Laboratory wind tunnels have also been used with physical models to measure the effectiveness of wind screens in reducing surface wind velocity.

A portable wind tunnel has been used to measure the control of coal pile wind erosion emissions by a 17% solution of Coherex® in water applied at an intensity of 3.4 L/m^2 (0.74 gal/yard^2), and a 2.8% solution of Dow Chemical M-167 Latex Binder in water applied at an average intensity of 6.8 L/m^2 (1.5 gal/yard^2).[1] The control efficiency of Coherex® applied at the above intensity to an undisturbed steam coal surface approximately 60 days before the test, under a wind of 15.0 m/s (33.8 mph) at 15.2 cm (6 in.) above the ground, was 89.6% for TP and approximately 62% for IP and FP. The control efficiency of the latex binder on a low volatility coking coal is shown in Figure 5-10.

5.4 ENCLOSURES

As described in Section 4, enclosures are an effective means by which to control fugitive particulate emissions from open dust sources. Enclosures can either fully or partially enclose the source. Full enclosures are also capable of either being evacuated through some type of dust collector (active) or nonevacuated (passive) as the case may be. Included in the category of partial enclosures are porous wind screens or barriers. This particular type of enclosure is discussed in detail below.

5.4.1 Design Considerations

With the exception of wind fences/barriers, a review of available literature reveals no quantitative information on the effectiveness of enclosures to control fugitive dust emissions from open sources. Types of passive enclosures traditionally used for open dust control include three-sided bunkers for the storage of bulk materials, storage silos for various types of aggregate material (in lieu of open piles), open-ended buildings, and similar structures. Practically any means that reduces wind entrainment of particles produced either through erosion of a dust-producing surface (e.g., storage silos) or by dispersion of a dust plume generated directly by a source (e.g., front-end loader in a three-sided enclosure) is generally effective in controlling fugitive particulate emissions. However, available data are not sufficient to quantify emission reductions.

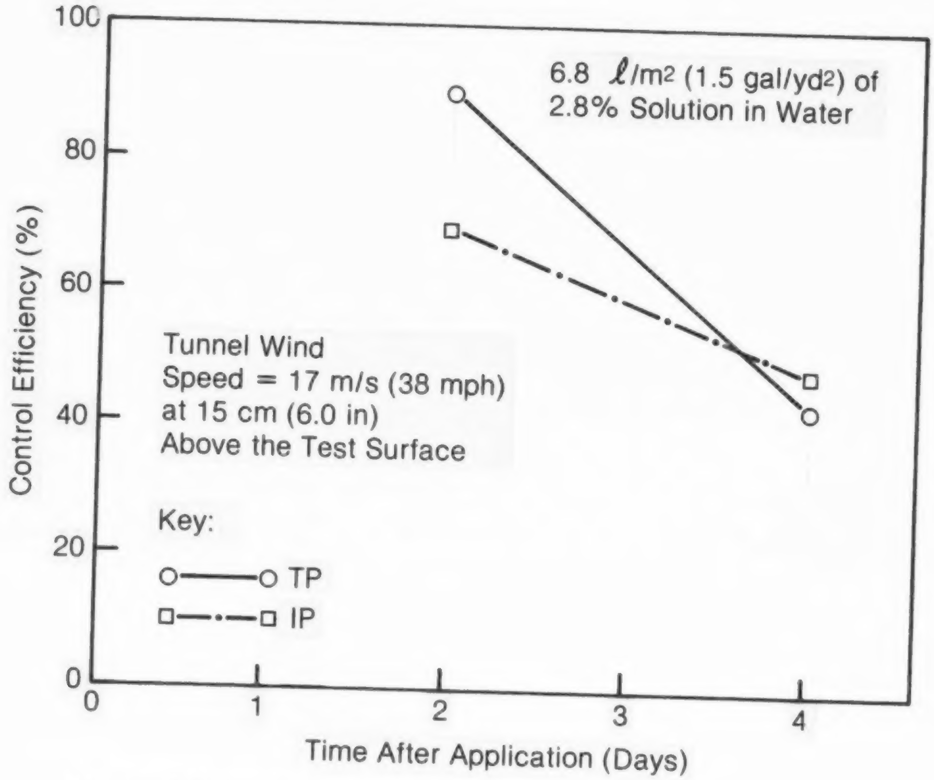


Figure 5-10. Decay in control efficiency of latex binder applied to coal storage piles[1]

Partial enclosures used for reducing windblown dust from large exposed areas and storage piles include porous wind fences and similar types of physical barriers (e.g., trees). The principle of the wind fence/ barrier is to provide an area of reduced wind velocity which allows settling of the large particles (which cause saltation) and reduces the particle flux from the exposed surface on the leeward side of the fence/barrier.

Wind fence/barriers can either be man-made structures or vegetative in nature. One type of screen material, made out of a textile fabric, has been used effectively first in Europe and then in the United States.[15] Wind breaks consisting of tree lines and other types of vegetation have also been used to shelter large open areas.[16]

5.4.2 Performance Data

A number of studies have attempted to determine the effectiveness of wind fences/barriers for the control of windblown dust under field conditions. Several of these studies have shown both a significant decrease in wind velocity as well as an increase in sand dune growth on the lee side of the fence.[16,17,18,19] The degree of emissions reduction varied from study to study ranging from 0 to a maximum of about 90% depending on test conditions.[18,20] A summary of available test data contained in the literature on the control achieved by wind fences/barriers is provided in Table 5-8.

Various problems have been noted with the sampling methodology used in each of the studies conducted to date. These problems tend to limit an accurate assessment of the overall degree of control achievable by wind fences/barriers for large open sources. Most of this work has either not thoroughly characterized the velocity profile behind the fence/barrier or adequately assessed the particle flux from the exposed surface.

5.5 WET SUPPRESSION SYSTEMS

Fugitive emissions from aggregate materials handling systems are frequently controlled by wet suppression systems. These systems use liquid sprays or foam to suppress the formation of airborne dust. The primary control mechanisms are those that prevent emissions through agglomerate formation by combining small dust particles with larger aggregate or with liquid droplets. The key factors that affect the degree of agglomeration and, hence, the performance of the system, are the coverage of the material by the liquid and the ability of the liquid to "wet" small particles. This section addresses two types of wet suppression systems--liquid sprays which use water or water/surfactant mixtures as the wetting agent and systems which supply foams as the wetting agent.

5.5.1 Basic Design Considerations

Liquid spray wet suppression systems can be used to control dust emissions from materials handling at conveyor transfer points. The wetting agent can be water or a combination of water and a chemical surfactant.

TABLE 5-8. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR WIND FENCES/BARRIERS

Material or control parameter	Reference No. 18	Reference No. 20
Type of fence/barrier	Textile fabric	Wooden cyclone fence
Porosity of fence/barrier	50%	50%
Height/length of fence/barrier	1.8 m/50 m	3 m/12 m
Type of erodable material	Flyash	Mixture of topsoil and coal
Material characteristics	$\%H_2O = 1.6$ $\% < 58$ µm = 14.7 $\% < 45$ µm = 4.6	Unknown
Incident wind speed	Average (no screen) = 4.3 m/s (9.7 mph) Average (upwind) = 5.32 m/s (11.9 mph)	Maximum = 27 m/s (60 mph)
Lee-side wind speed	Average = 2 m/s (4.0 mph) or 64% reduction	Unknown
Particulate measurement technique[a]	U/D - Hi-vol and Hi-vol w/SSI (11 tests)	U/D - Bagnold catchers (1 test)
Test data rating[b]	C	C
Measured particulate control[c] efficiency	TP = 64% (average) TSP = 0% (average)	TP = 88% (average)

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[a] U/D = Upwind/downwind sampling.
Hi-Vol = High volume air sampler; Hi-vol w/SSI = High volume air sampler with 15 µmA size-selective inlet (SSI)

[b] Data rated using criteria specified in Section 4.4.

[c] TP = Total particulate matter
TSP = Total suspended particulate matter (particles < ~ 30 µmA)

This surfactant, or surface active agent, reduces the surface tension of the water. As a result, the quantity of liquid needed to achieve good control is reduced. For systems using water only, addition of surfactant can reduce the quantity of water necessary to achieve a good control by a ratio of 4:1 or more.[21,22]

The design specifications for wet suppression systems are generally based on the experience of the design engineer rather than on established design equations or handbook calculations. Some general design guidelines that have been reported in the literature as successful are listed below:

1. A variety of nozzle types have been used on wet suppression systems, but recent data suggest that hollow cone nozzles produce the greatest control while minimizing clogging.[23]
2. Optimal droplet size for surface impaction and fine particle agglomeration is about 500 μm; finer droplets are affected by drift and surface tension and appear to be less effective.[24]
3. Application of water sprays to the underside of a conveyor belt improves the performance of wet suppression systems at belt-to-belt transfer points.[25]

Micron-sized foam application is an alternative to water spray systems. The primary advantage of foam systems is that they provide equivalent control at lower moisture addition rates than spray systems.[25] However, the foam system is more costly and requires the use of extra materials and equipment. The foam system also achieves control primarily through the wetting and agglomeration of fine particles. The following guidelines to achieve good particle agglomeration have been suggested:[26]

1. The foam can be made to contact the particulate material by any means. High velocity impact or other brute force means are not required.
2. The foam should be distributed throughout the product material. Inject the foam into free-falling material rather than cover the product with foam.
3. The amount applied should allow all of the foam to dissipate. The presence of foam with the product indicates that either too much foam has been used or it has not been adequately dispersed within the material.

5.5.2 Performance Data

Available data for both water spray and foam wet suppression systems are presented in Tables 5-9 and 5-10, respectively. The data primarily included estimates of control efficiency based on concentrations of total particulate or respirable dust in the workplace atmosphere. Some data on mass emissions reduction are also presented. The data should be viewed with caution in that test data ratings are generally low and only minimal data on process or control system parameters are presented.

The data in Tables 5-9 and 5-10 do indicate that a wide range of efficiencies can be obtained from wet suppression systems. For conveyor transfer stations, liquid spray systems had efficiencies ranging from 42 to 75%, while foam systems had efficiencies ranging from 0 to 92%. The data are not sufficient to develop relationships between control or process parameters and control efficiencies. However, the following observations relative to the data in Tables 5-9 and 5-10 are noteworthy:

1. The quantity of foam applied to a system does have an impact on system performance. On grizzly transfer points, foam rates of 7.5 ft^3 to 10.5 ft^3 of foam per ton of sand produced increasing control efficiencies ranging from 68 to 92%.[27] Foam rates below 5 ft^3 per ton produced no measurable control.
2. Material temperature has an impact on foam performance. At one plant where sand was being transferred, control efficiencies ranged from 20 to 65% when 120°F sand was handled. When sand temperature was increased to 190°F, all control efficiencies were below 10%.[27]
3. Data at one plant suggest that underside belt sprays increase control efficiencies for respirable dust (56 to 81%).[25]
4. When spray systems and foam systems are used to apply equivalent moisture concentrations, foam systems appear to provide greater control.[27] On a grizzly feed to a crusher, equivalent foam and spray applications provided 68% and 46% control efficiency, respectively.

5.6 PLUME AFTERTREATMENT

The injection of charged or uncharged water droplets into a dust plume can be effective means by which to settle the suspended particles.

TABLE 5-9. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR WATER SPRAYS

Reference No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Test data rating[b]	Control efficiency[c] (%)
25	Chain feeder to belt transfer	Coal	3 ft drop, 8 tons coal per load	8 Sprays, 2.5 gpm, above belt only	Personnel samplers, Type 1 test scheme	10	C	RP 56 TP 59
				8 Sprays, 2.5 gpm + 1 spray on underside of belt	Personnel samplers, Type 1 test scheme	4	C	RP 81 TP 87
	Belt-to-belt transfer	Coal	Not specified	8 Sprays, 2.5 gpm, above belt only[d]	Personnel samplers, Type 1 test scheme	10	C	RP 53
				8 Sprays, 2.5 gpm + 1 spray on underside of belt[d]	Personnel samplers, Type 1 test scheme	4	C	RP 42
27	Grizzly transfer to bucket elevator	Run of mill sand	Not specified	Liquid vol. 757 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 46
				Liquid vol. 1,324 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 58
				Liquid vol. 1,324 mL[e]	Personnel samplers, Type 1 test scheme	NA	C	RP 54
				Liquid vol. 1,324 mL[f]	Personnel samplers, Type 1 test scheme	NA	C	RP 54
28	Conveyor transport and transfer	Coal	2 belts 0.91 m and 1.07 m widths, ~ 500 m length	3 Spray bars/belt, underside of tail pulley, 5-10 cc H_2O/sec per bar, Delevan "fanjet" sprays	Personnel samplers, Type 1 test scheme[g]	NA	D	RP 65-75

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[a] RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.

[b] Test rating scheme defined in Section 4.4.

[c] TP = Total Particulate; RP = Respirable Particulate.

[d] Control applied at a point five transfers upstream.

[e] Water + 1.5% surfactant.

[f] Water + 2.5% surfactant.

[g] Individual test values not specified; no airflow data or QA/QC data.

TABLE 5-10. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR FOAM SUPPRESSION SYSTEMS

Reference No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Test data rating[b]	Control efficiency[c] (%)
27	Belt-to-belt transfer	30-mesh glass sand	Sand temp. ~ 120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	C	RP 20[d]
	Belt-to-bin transfer	30-mesh glass sand	Sand temp. ~ 120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	C	RP 33[d]
	Bulk loadout	30-mesh glass sand	Sand temp. ~ 120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	C	RP 65[d]
	Screw-to-belt transfer	Cleaned run-of-mine sand	174 tons/hr Sand temp. ~ 190°F	Moisture = 0.25%	Grav/RAM samplers, Type 1 scheme	4	C	RP 10[d]
	Bucket elevator discharge	Cleaned run-of-mine sand	179 tons/hr Sand temp. ~ 190°F	Moisture = 0.18%	RAM/personnel samplers, Type 1 test scheme	5	C	RP 8[d]
	Belt-to-belt transfer	Cleaned run-of-mine sand	193 tons/hr Sand temp. ~ 190°F	Moisture = 0.18%	RAM/personnel samplers, Type 1 test scheme	8	C	RP 7[d]
	Feeder bar discharge	Cleaned run-of-mine sand	191 tons/hr Sand temp. ~ 190°F	Moisture = 0.19%	RAM/personnel samplers, Type 1 test scheme	6	C	RP 2[d]
	Grizzley transfer to bucket elevator	Dried run of mine sand	Not specified	Foam rate = 10.5 ft^3 /ton sand Liquid rate = 0.38 gal/min	Personnel samplers, Type 1 test scheme	2	C	RP 92
				Foam rate = 8.2 ft^3 /ton sand Liquid rate = 0.34 gal/min	Personnel samplers, Type 1 test scheme	1	C	RP 74
				Foam rate = 7.5 ft^3 /ton sand Liquid rate = 0.20 gal/min	Personnel samplers, Type 1 test scheme	1	C	RP 68

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[a] RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.

[b] Test rating scheme defined in Section 4.4.

[c] RP = Respirable Particulate.

[d] Efficiency based on concentrations only.

TABLE 5-10. (concluded)

Reference No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Test data rating[b]	Control efficiency[c] (%)
25	Chain feeder to belt transfer	Coal	3-ft drop, 8 tons coal per load	50 psi H_2O, 2.5% reagent, 4 nozzles 15-20 cfm foam applied[d]	Personnel samplers, Type 1 test scheme	9	C	RP 96 TP 92
	Belt-to-belt transfer	Coal	Not specified	50 psi H_2O, 2.5% reagent, 4 nozzles 15-20 cfm foam applied[e]	Personnel samplers, Type 1 test scheme	9	C	RP 71
27	Grizzley	Dried run-of-mine sand	Not specified	Foam rate = 4.8 ft³ /ton sand Liquid rate = 0.18 gal/min	Personnel samplers, Type 1 test scheme	2	C	RP 0
				Foam rate = 2.6 ft³ /ton sand Liquid rate = 0.13 gal/min	Personnel samplers, Type 1 test scheme	2	C	RP 0
				Liquid vol. 1,420 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 91
				Liquid vol. 1,300 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 73
				Liquid vol. 764 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 68

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[a] RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.

[b] Test rating scheme defined in Section 4.4.

[c] TP = Total Particulate; RP = Respirable Particulate.

[d] Efficiency based on concentrations only.

[e] Control applied at a point five transfers upstream.

In this section, available test data on plume aftertreatment systems will be provided as a guide to the environmental professional in the application of such technology to the control of fugitive particulate emissions from open sources.

5.6.1 Basic Design Considerations

A number of important parameters must be considered in the proper application of plume aftertreatment using plain water. Since impaction is the primary mechanism by which the water droplets capture suspended dust particles, the size and velocity of the droplets injected into the plume are critical to proper system design. According to the U.S. Bureau of Mines (BOM), the optimum drop size for the capture of airborne respirable dust ($\sim < 10$ µm) is approximately 200 µm.[29,30] The velocity of the droplets injected into the dust plume should also be maximized to the greatest extent possible.

Guidelines on the proper design and operation of water spray systems have been published by the BOM.[29,30] These guidelines include proper nozzle selection, location of nozzles for optimum coverage of the dust plume, the design of filtration systems to reduce nozzle wear and clogging. The reader is referred to these documents for assistance in the application of plume aftertreatment systems using plain water.

In the past several years, electrostatics has been used to augment traditional water sprays for plume aftertreatment. Most mechanically generated aerosol particles acquire a slight electrostatic charge.[31] By injecting a fog of oppositely charged water droplets into the plume, a significant enhancement in the capture and removal process can be achieved (especially for particles in the 1 to 2 µm size range.)[32,33]

Two companies currently market a commercial version of electrostatic fogger. These units utilize induction charging and generally follow the design originally developed by Hoenig.[31] In addition to the commercial foggers, an experimental unit (CFG) was developed under EPA sponsorship by a California firm. This experimental model uses direct charging and a rotary atomizer for the generation of charged fog.[34]

The efficiency at which charged fog captures airborne particles depends on several parameters: volumetric ratio (volume of spray to volume of dust plume); contact time; droplet size; and charge-to-mass ratio (for water droplets and dust particles). At present insufficient data are available to quantify the relationships between these control parameters.

Since use of charged fog for the control of fugitive dust has been tested only on a limited basis, relatively little data are available on field performance. The application of charged fog has been suggested for use in the crushed stone and smelting industries.[35,36]

5.6.2 Performance Data

Plume aftertreatment systems using plain water have been extensively investigated in the laboratory by the U.S. Bureau of Mines.[30,31,32,37,38] These studies have included an evaluation of both water sprays and steam for the control of respirable particles. Most of this work was conducted in a wind tunnel with dust concentrations measured by wet impingers upstream and downstream of the spray injection point. BOM research has indicated a general reduction in respirable dust concentrations in the range of 20-60% using water sprays alone with an additional 14% increase in efficiency when steam and water sprays are used concurrently.[31,37] When surfactants were added to the water prior to atomization, a 10-15% increase in efficiency was achieved in the capture of airborne respirable dust as compared to water alone.[39]

A number of laboratory studies have also been conducted on the use of charged water droplets (fog) for plume aftertreatment. Wind tunnel (or chamber) studies have been performed by Hoenig, Kinsey, and McCoy under the sponsorship of either the EPA or BOM.[32,33,40,41] Reductions in dust concentration achieved by charged fog vary significantly from study to study, depending on test conditions, type of dust and particle size. Generally, a 40-80% reduction in dust concentration seems to be typical over most particle size ranges and test conditions. A significant enhancement in dust capture efficiency was determined in the various studies for particles in the smaller size ranges (i.e., < 1-2 μmA) due to the electrostatic forces which act on these size particles.

In addition to wind tunnel or chamber experiments, a number of investigators have also conducted field studies to measure the effectiveness of charged fog to control fugitive dust. Hoenig conducted some field investigations as part of his original work with subsequent programs conducted by Mathai, McCoy, and Brookman.[31,33,39,41]

As expected, control efficiencies determined in field tests are generally lower than those measured in the laboratory. Because all of the field tests suffer from one or more deficiencies in experimental technique, data quality is limited. Table 5-11 summarizes the available control efficiency data for plume aftertreatment systems.

5.7 OTHER OPEN SOURCE CONTROLS

There are a number of open source control techniques which have not as yet been evaluated on a quantitative basis, and thus no substantive test data are available for control efficiency. These methods include: physical stabilization of unpaved surfaces; mud/dirt carryout control for construction and demolition; and modified tilling practices for agricultural operations. To assist the environmental professional in the use of these techniques, Table 5-12 presents literature references which describe these methods in further detail. The reader is directed to these references for guidance in the application of these methods for open source control.

TABLE 5-11. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR PLUME AFTERTREATMENT SYSTEMS (OPEN DUST SOURCES)[a]

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Fogger system[b]	Measurement technique[c]	Number of tests[d]	Test data rating[e]	Average control efficiency[f]
31	Belt conveyor[g]	Quarry stone	Not specified	2-Ransburg REA foggers at 180° from each other along direction of belt travel; WFR = 94.6 cc/min total AF = 5.7 m^3/hr total	Near belt: 7-stage Anderson cascade impactor	4	C	< 9 µm A ≅ 70%
	Belt conveyor	Copper concentrate	Not specified	1-Ransburg REA fogger mounted above belt discharge; WFR = 30-60 cc/min AF = not specified	Near belt: GCA model RDM-101 w/cyclone	6	D	TP = 58-72% RP = 64-77%
	Drop box	Copper concentrate	Not specified	1-Ransburg REA fogger in drop box enclosure; WFR = Not specified AF = Not specified	Inside drop box: GCA model RDM-101 w/cyclone	18	C	RP = 65.4%
	Boxcar unloading	Silica sand	Not specified	4-Ransburg REA foggers located 90° apart around source; WFR = 30 cc/min/fogger AF = Not specified	Inside boxcar: MSA personnel sampler	2	D	RP = 89%
33	Front loader dump into partially enclosed hopper	Bentonite ore 8% < 37 µm	3-sided enclosure 10 dumps/25 min enclosure volume ≅ 40 m^3	1-AeroVironment CFG mounted at end of enclosure; WFR = 60 L/hr AF = Not specified	Single pt: Hi-vol w/cyclone and 2-stage	44	C	< 7.3 µmA = 44.5% < 1.8 µmA = 48.1%
39	Belt conveyor	Crushed ore	Conveyor width = 1.5 m Belt speed = 152 m/min Ventilation rate = 15-61 m/min	6-Keystone Dynamics Model 109s located 1.5 m above belt (spray concurrent w/direction of belt movement); WFR = 300 cc/min/fogger AF = supply pressure = 344 kPa	U/D: GCA model RAM-1 w/cyclone	6	D	RP = 0%

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[a] Includes only results of field testing.

[b] The Ransburg, Ritten, and Keystone foggers are based on the original Hoenig design which uses induction charging and commercial spray nozzles. The AeroVironment prototype units use a rotary atomizer and direct charging to produce charged fog. AeroVironment CFG = 200 µm drops; $1.2(10)^{-6}$ C/g @ 4 kV; 16-24 m^3 spray volume. Ritten Fogger IV = ~ 60 µm drops @ 75 L/hr; $0.11(10)^{-6}$ C/g @ 12.5 kV. WFR = water flow rate; AF = airflow to fogger(s).

[c] MSA personnel sampler = 10 mm nylon cyclone followed by a 37-mm filter cassette. 10 mm nylon cyclone also used on GCA Model RDM-101 and RAM-1 continuous instruments. U/D = measurements taken upstream and downstream of the point where charged fog is injected into conveyor tunnel. Hi-vol = standard high volume air sampler; Hi-vol w/SSI = high volume air sampler equipped with Sierra 15 µmA size-selective inlet; Hi-vol w/cyclone and impactor = high volume air sampler equipped with Sierra Model 230CP cyclone precollector and Sierra Model 230 slotted cascade impactor.

[d] Total number of uncontrolled and controlled tests conducted.

[e] Data rated using criteria specified in Section 4.4.

[f] TP = Total Particulate; RP = Respirable Particulate; TSP = Total Suspended Particulate. Efficiency ranges include average efficiency for both positively/ negatively charged fog.

[g] Located inside a building.

TABLE 5-11. (concluded)[a]

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Fogger system[b]	Measurement technique[c]	Number of tests[d]	Test data rating[e]	Average control efficiency[f]
41	Dump into primary crusher (test No. 1)[g]	Quarry rock (basalt)	45 Mg/truck load Unloading time = 30-60 sec Pit volume = 192 m³	2-Ritten Fogger IVs at 90° from each other (one upwind/one downwind); WFR = 53-78 L/hr/fogger AF = 1.4-4.8 m³/hr/fogger	(32) Downwind: Hi-vol; Hi-vol w/SSI; Hi-vol w/4-stage impactor[i]	32	C	TSP = 57-58% IP = 46-53%
	Belt-to-belt transfer (open) (test No. 6)	Sinter fines	Drop height = 1.2 m	2-Ritten Fogger IVs 2-AeroVironment CFGs located 180° from each transfer point; WFR = 56.8 L/hr/fogger AF = 3 8 m³/hr/Ritten fogger; 50% max. (AV)	Above and next to source: Hi-vol; Hi-vol w/SSI; Hi-vol w/cyclones and 4-stage impactor[h]	100	C	< ~ 6 µmA = 31-55% < 2-3 µmA = 0-93% (all foggers)
	Crusher conveyor (test No. 7)	Crushed limestone (< 10 cm)	Conveyor tunnel = 3 m dia.	1-Ritten Fogger IV 2-AeroVironment CFGs spray injected into tunnel counter-current to direction of belt movement; WFR = 113.5 L/hr (Ritten); 56.8 L/hr/AV fogger AF = 113.5 L/hr (Ritten); 50% max. (AV)	Above and next to source: Hi-vol; Hi-vol w/SSI; Hi-vol w/cyclone and 4-stage impactor[h,i]	134	C	TSP = 13-35% IP = 0-28% < 6 mA = 2-30% < 2-3 µmA = 31-50% (all foggers)

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[a] Includes only results of field testing.

[b] The Ransburg, Ritten, and Keystone foggers are based on the original Hoenig design which uses induction charging and commercial spray nozzles. The AeroVironment prototype units use a rotary atomizer and direct charging to produce charged fog. AeroVironment CFG = 200 µm drops; $1.2(10)^{-6}$ C/g @ 4 kV; 16-24 m³ spray volume. Ritten Fogger IV = ~ 60 µm drops @ 75 L/hr; $0.11(10)^{-6}$ C/g @ 12.5 kV. WFR = water flow rate; AF = airflow to fogger(s).

[c] MSA personnel sampler = 10 mm nylon cyclone followed by a 37-mm filter cassette. 10 mm nylon cyclone also used on GCA Model RDM-101 and RAM-1 continuous instruments. U/D = measurements taken upstream and downstream of the point where charged fog is injected into conveyor tunnel. Hi-vol = standard high volume air sampler; Hi-vol w/SSI = high volume air sampler equipped with Sierra 15 µmA size-selective inlet; Hi-vol w/cyclone and impactor = high volume air sampler equipped with Sierra Model 230CP cyclone precollector and Sierra Model 230 slotted cascade impactor.

[d] Total number of uncontrolled and controlled tests conducted.

[e] Data rated using criteria specified in Section 4.4.

[f] TP = Total Particulate; RP = Respirable Particulate; TSP = Total Suspended Particulate; IP = Inhalable Particulate. include average efficiency for both positively/negatively charged fog.

[g] Truck dump into crusher pit.

[h] No background samples collected during test program.

[i] Samplers located both in tunnel next to conveyor and above tunnel exit.

TABLE 5-12. LITERATURE REFERENCES FOR OPEN SOURCE CONTROLS WHERE NO TEST DATA ARE AVAILABLE

Control method	Literature reference(s)[a]
Physical stabilization	15, 42, 43
Vegetative stabilization	15, 16, 44
Mud/dirt carryout for construction and demolition	45
Agricultural tilling	46, 47, 48

[a] Refers to list of references at the end of Section 5.

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SECTION 6
ESTIMATION OF CONTROL SYSTEM PERFORMANCE — PROCESS SOURCES

Industrial process fugitive emissions pose a dual problem for the control engineer. These emissions contribute to degradation of ambient air quality, and they can be a source of worker exposure to toxic or nuisance contaminants. Consequently, control systems can be designed to reduce atmospheric emission rates and/or maintain low contaminant concentrations in the worker breathing zone. Some control systems address both objectives, while some address one at the expense of the other.

Fugitive emissions control systems have been installed on a wide variety of process sources. Because these systems are designed with diverse objectives and because individual process conditions vary, each fugitive control system is unique in its design and operation. Some of the factors which affect the choice of a system and selection of design and operating parameters are size of the process, physical and chemical characteristics of the emissions stream, worker or equipment access requirements for the process, structural constraints (fugitive control systems often are retrofit to existing processes), and regulatory requirements.

The variation in control system design and operation is reflected in the extreme variation in the performance of those systems. This section presents the available information on process fugitive emissions control system performance. Because the control systems do vary widely in their performance and these variations are not fully understood, the material in this section should be used with caution. The performance data provided in later subsections can provide the basis for engineering analyses of the potential performance of a system. However, control efficiencies for a system should not be applied directly to other systems.

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Assessment of the performance capability of a control system for a specific industrial process requires a structured approach. Key process and control system parameters that affect performance must be defined based on general design principles. Available data on control system performance then can be evaluated with respect to these key parameters.

The alternative approaches available for the control of process fugitive emissions, as reviewed in Chapter 4, include:

1. Wet Suppression
    - Water sprays (with and without chemical additives)
    - Foams
2. Enclosures
    - Passive enclosures (without evacuation)
    - Active enclosures (with evacuation to a dust collector)
3. Hooding Systems
    - Receiving hoods
        - Canopy hoods
        - Close capture hoods
        - Hoods for mechanically directed plumes
    - Capture hoods
        - Side draft hoods
        - Push/pull hooding systems
        - High velocity low volume hoods
        - Close capture hoods
4. Plume Aftertreatment
    - Fine water sprays
    - Electrostatic foggers

Wet suppression and passive enclosures are preventive measures, whereas hooding systems and plume aftertreatment are capture/removal methods. All of these controls are designed to be continuously applied.

This section presents the data needed to assess the four types of process fugitive emissions control systems--wet suppression, enclosures, hooding systems, and plume aftertreatment. For each type of system, basic design considerations are described, key control parameters are identified, and available performance data are presented. Two types of performance data are included --those based on environmental measurements of reduction in mass emissions and those based on measurements of workplace concentrations.

Finally, a brief discussion of other control techniques for which test data are not available is also presented.

6.1 WET SUPPRESSION SYSTEMS

The use of wet suppression for the control of fugitive emissions has been discussed previously in Section 5. In this section, the application of wet suppression systems for process sources will be addressed. Types of processes which typically utilize wet suppression include crushers, screens, and other size reduction operations.

6.1.1 Basic Design Considerations

As mentioned previously, either water, water plus a surfactant, or aqueous foams can be used in wet suppression systems. Since each process is unique, the specific design of the system and the wetting agent used will vary from source to source. However, some general guidelines reported in the literature include:

1. On primary and secondary crushers, water-only systems require greater than 5% moisture, while water/surfactant systems can achieve reasonable control with only 1% moisture.[1,2]
2. Tertiary crushing will require 4 to 5% moisture for water/surfactant systems.[3]
3. Nozzles on crushers should be located between 3 and 6 ft from moving materials to minimize nozzle damage and reduce the chance of water drift.

6.1.2 Performance Data

Available test data for both water spray and foam wet suppression systems are presented in Table 6-1. The control efficiency data shown are based on either a downwind tracer technique or respirable dust sampling in the workplace atmosphere before and after control application. In both cases, the data are extremely limited and of somewhat low quality. Therefore, caution is advised when utilizing the information contained in Table 6-1.

TABLE 6-1. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR WATER SPRAYS AND FOAM SUPPRESSION

Reference No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Test data rating[b]	Control efficiency[c] (%)
4	Crusher	Gypsum	Not specified	3 Nozzles (2 x 1/32 in. flat), 200 parts H_2O/1 part foaming agent	RAM sampler without cyclone; Type 1 test scheme	NA	D	RP 27[d]
5	Secondary crusher	Limestone	424 tons/hr, 3 in. material size	Water spray - not specified	Downwind tracer; Type 1 test scheme[e]	19	B	TSP 83 PM_{10} 92
	Tertiary crusher	Limestone	127 tons/hr, 5/8 in. nominal material size	Water spray - not specified	Downwind tracer; Type 1 test scheme	18	B	TSP 77 PM_{10} 83

[a] RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.

[b] Test rating scheme defined in Section 4.4.

[c] TSP = Total Suspended Particulate, PM_{10} = Particulate Matter less than 10 μm aerodynamic diameter; RP = Respirable Particulate.

[d] Efficiency based on concentrations only.

[e] No calibration or wind data.

A shown in Table 6-1, the test data on crusher controls are mixed. One test indicated that foam applied at the crusher inlet results in only 27% control efficiency.[4] Another test indicated that water sprays provided 83% control for primary and secondary crushers and 77% control for tertiary crushers.[5]

6.2 ENCLOSURES

Enclosures can be used to contain or capture emissions from such processes as crushing, screening, material cleaning, and material transport. The enclosures used to control these emissions can be classified as one of two types--active enclosures in which air is evacuated to an air pollution control device and passive enclosures without evacuation. No substantive mass emissions test data were identified for either active or passive enclosures. Further, no information on design guidelines for enclosures was obtained. Active enclosures are described in more detail as a component of capture/collection systems in Section 6.3.1.

6.3 CAPTURE/COLLECTION SYSTEMS

Capture/collection systems are frequently used in industrial facilities to improve the work environment and reduce air emissions. The design of each capture collection system is unique. It is dependent on the specific operations to be controlled, the level of control required and physical constraints of plant operations. While these systems are unique, they all have three basic components: a hood or enclosure to capture or contain particulate emissions; a ventilation system comprising the fan and ductwork to provide airflow for capture and transport of the particulate matter; and an air pollution control device. Each of these components is important to the performance of the fugitive emission control system.

6.3.1 Basic Design Considerations

While only limited test data have been developed for capture collection systems, a large body of information is available on design guidelines.[6-9]

However, adherence to these guidelines does not assure the complete capture of the emissions. Although detailed design guidelines are not repeated here, the following paragraphs do describe basic hooding design principles.

The objective of the exhaust hood is to capture particulate emissions at the source before they escape to the plant environment or atmosphere. The term hood is used in the broad sense to mean all suction openings including suspended hoods, enclosures, side draft hoods, and open duct faces. The hood acts to capture particulate via three mechanisms--enclosing the emitting source(s) (enclosure), locating the hood so that buoyant or mechanical forces imparted by the process direct the emissions into the hood (receiving hood), and using airflow generated by the hood to draw the emissions stream into the hood (capture hood). Hoods often use more than one capture mechanism.

Regardless of mechanism, the two primary parameters involved in the design of effective local exhaust or hooding systems are: (a) locating the hood (defined in the broad sense described above) to contain emitted particulate as much as possible; and (b) providing adequate flow to capture any particulate not contained by the hood and prevent the escape of all particulate from the hood. The goal of hood design is to install a hood or enclosure that provides effective particulate control at the minimum exhaust volume.

The first objective in locating the hood is to enclose the emissions source as much as possible. The more complete the enclosure, the more economical and effective the control system will be. In fact, one design method is to start with a complete enclosure of the operation to be controlled and add openings as required by the process.

When complete enclosure of the operation is not feasible, the following practices are generally followed. All maintenance openings are located away from the natural path of particulate that results from material flow or dust splash. Inspection and maintenance openings are provided with doors or rubber flaps if possible. Openings for material flow are often equipped with flaps of rubber, canvas, or other pliable material.

Airflow exhausted from a local capture hood installed on an operation involving material movement serves two purposes: the exhaust must overcome induced airflow created by material motion; and the exhaust must provide sufficient velocity to capture particulate which escapes the confines of the hood. The predominant function is dependent on hood type. If an enclosure is used, control of induced airstreams is the primary objective. If the operation requires an exterior hood, particulate capture is the primary airflow function.

For those systems which can be controlled by complete or partial enclosure, the airflow at the hood should be sufficient to overcome induced air currents inherent to the process and to provide an inward air velocity through all openings of about 50 to 200 ft/min.[7] The volumes needed to overcome induced air currents associated with specific processes are discussed below. The flow needed to provide adequate velocities at openings can be calculated by the formula:

$$Q = A\ V \qquad (6\text{-}1)$$

where:

Q = required airflow (ft^3/min)

A = cross-sectional area of openings (ft^2)

V = required velocity at openings (ft/min)

Material transport creates an induced airflow which must be overcome to effectively control fugitive emissions. Anderson has developed the following equation for calculating induced airflow at transfer points.[8]

$$Q = 10.0\ A_u \sqrt[3]{\frac{RS^2}{D}} \qquad (6\text{-}2)$$

where:

Q = induced airflow (ft^3/min)

A_u = feed opening (ft^2)

R = rate of material flow (tons/hr)

S = height of fall (ft)

D = average particle diameter (ft)

The objective of a capture hood is to provide a capture velocity of 50 to 75 ft/min at the farthest capture point from the hood. The total flow required to achieve this velocity is:

$$Q = V\ (10\ X^2 + A) \qquad (6\text{-}3)$$

where:

Q = required airflow (ft^3/min)

V = required capture velocity (ft/min)

X = distance from hood to farthest null point (ft)

A = cross-sectional area of hood (ft^2)

Receiving hoods capture particulate as it is directed from the source by thermal or mechanical forces. Examples are canopy hoods for furnace charging and tapping emissions and close capture hoods on grinding equipment. Key design considerations are locating the hood so that the complete exhaust stream is directed to the hood and generating an airflow greater than the induced stream that is directed into the hood. Plume size and cross draft problems are major concerns in designing receiving hoods.

6.3.2 Performance Data

The performance of the capture/collection system, as defined by control efficiency, is a combination of the capture efficiency at the source and the collection efficiency of the air pollution control device. Since data on collection efficiency have been summarized in detail in previous manuals, they will not be addressed here.[10,11] The discussion will focus on the capture efficiency of hoods and enclosures.

Few test data are available on the performance of hoods and enclosures. Estimates based on visible emissions observations do suggest that the performance varies widely from plant to plant. Process and control system parameters which contribute to this variation include location of the hood with respect to the source, airflows in the vicinity of the source, process and plume temperature, source mobility, and air volume flow rates. This combination of limited test data and highly variable performance makes any general assessment of capture efficiency quite speculative. A separate guidance document specifically related to the design of hood capture systems has been developed under another EPA contract to which the reader is directed for further information.[12]

Available data on control efficiencies for capture collection systems are presented in Table 6-2.[13,14] The data from the Banbury mixer highlight the impact of plant conditions on hood performance. When an employee cooling fan in the vicinity of the mixer was turned on, capture efficiency was reduced from 90 to 40%. The data also highlight the importance of distance between the source and the hood on performance. When the hood was moved from 1 to 3 m from the hood, efficiency was reduced from 90 to 70%.

6.4 PLUME AFTERTREATMENT

The injection of charged or uncharged water droplets into a dust plume can effectively remove suspended particulate matter. Plume aftertreatment includes the use of water sprays, steam, and charged water droplets (fog). Since this technology has been described in detail above, any further discussion of such will not be presented here.

6.4.1 Basic Design Considerations

The same basic design parameters defined for plume aftertreatment of open dust sources apply to the use of aftertreatment systems for process sources. Droplet size, charge-to-mass ratio, and the method of applying an electrostatic charge to the droplets, all must be taken into consideration. The ambient temperature has a direct effect on droplet size and thus charge-to-mass ratio.

6.4.2 Performance Data

Available test data for plume aftertreatment have been summarized in Table 6-3.[15-17] As shown, very limited data are available on the performance of aftertreatment systems as applied to process fugitive sources. At present the data are not adequate to quantify relationships between control/process parameters and performance.

TABLE 6-2. SUMMARY OF CONTROL EFFICIENCY DATA FOR CAPTURE/COLLECTION SYSTEMS

Reference No.	Type of process	Type of material	Process design/ operating parameters	Capture mechanism/ air pollution control device	Control system parameters	Measurement technique	No. of tests	Test data rating[a]	Control efficiency[b] (%)
13	Aluminum reduction cell-anode	Molten aluminum	Not specified	Close capture hood/ NA	Flow = 50 m³/min	Tracer (H_2) in control system duct	NA	D	70
					Flow = 80 m³/min	Tracer (H_2) in control system duct	NA	D	77
					Flow = 120 m³/min	Tracer (H_2) in control system duct	NA	D	91
					Flow = 160 m³/min	Tracer (H_2) in control system duct	NA	D	98
	Aluminum reduction cell tapping	Molten aluminum	Not specified	Close capture/NA	Flow = 120 m³/min	Tracer (H_2) in control system duct	NA	D	96
	Anode removal	Molten aluminum	Not specified	Close capture/NA	Flow = 120 m³/min	Tracer (H_2) in control system duct	NA	D	86
14	Banbury mixer	NA	Not specified	Capture hood/NA	Hood 1 m from mixer, cooling fan off	Tracer (oil mist) in control system duct	NA	D	90
					Hood 1 m from mixer, cooling fan on	Tracer (oil mist) in control system duct	NA	D	40
					Hood 3 m from mixer, cooling fan off	Tracer (oil mist) in control system duct	NA	D	70

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[a] Test rating scheme defined in Section 4.4.

[b] Capture efficiency measured indirectly with a tracer; no measurements of source emissions.

TABLE 6-3. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR PLUME AFTERTREATMENT SYSTEMS (PROCESS SOURCES)[a]

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Fogger system[b]	Measurement technique[c]	Number of tests[d]	Test data rating[e]	Average control efficiency[f]
15	Bag splitting hood	Cream-tex 32% alumina 52% SiO_2	Not specified	2-Ransburg REA foggers located inside hood; WFR = 45 cc/min total; AF = 4.3 m^3/hr total	Inside hood: MSA personnel sampler	6	C	RP=45-61%
16	Cotton gin	Cotton fibers	Not specified	Ritten Fogger II prototype(s); WFR = 50 cc/min AF = 1.13 m^3/hr	Gravimetric samples; instrument unspecified	10	D	TP=83-88%
	Cotton press	Cotton fibers	Not specified	Ritten Fogger II prototype(s); WFR = 100 cc/min AF = 4.5 m^3/hr	Gravimetric samples @ top and center of press; instrument unspecified	12	D	TP=33-71%
17	Coke screen (Test No. 4)[g]	Coke	1 run = 2-6 min Screen area = 1.8 m x ~ 4.0 m	2-Ritten Fogger IVs - one spraying across screen and one spraying down on screen; WFR = 53-91 L/hr/fogger AF = 1.4-4.8 m^3/hr/fogger	Near screen: Hi-vol; Hi-vol w/ssI; Hi-vol w/ SSI and impactor[h]	52	C	TSP=27-45% IP=15-33%
	Torch cutting operation (Test No. 5)[g]	304 stainless steel slabs	Cutting rate = 9.5 cm/min Cutting time = 40 min Slab thickness = 0.13 m 4 circles cut/slab	2-Ritten Fogger IVs 2-AeroVironment CFGs (pos. fog only) spraying across source; WFR = 58.6 L/hr/Ritten fogger; 56.8-75.6 L/hr/ AV fogger AF = 3.6 m^3/hr/Ritten fogger; 50% maximum (AV)	Above source: Hi-vol; Hi-vol w/SSI; Hi-Vol w/SSI and 4-stage impactor[h]	132	D	TSP=58%[i] IP=59% (Ritten w/ neg. fog)

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[a] Includes only results of field testing.

[b] The Ransburg, Ritten, and Keystone foggers are based on the original Hoenig design which uses induction charging and commercial spray nozzles. The AeroVironment prototype units use a rotary atomizer and direct charging to produce charged fog. AeroVironment CFG = 200 μm drops; $1.2(10)^{-6}$ C/g @ 4 kV; 16-24 m^3 spray volume. Ritten Fogger IV = ~ 60 μm drops; $0.11(10)^{-6}$ C/g @ 12.5 kV. WFR = water flow rate. AF = airflow to fogger(s).

[c] MSA personnel sampler = 10 mm nylon cyclone followed by a 37-mm filter cassette. 10 mm nylon cyclone also used on GCA Model RDM-101 and RAM-1 continuous instruments. U/D = measurements taken upstream and downstream of the point where charged fog is injected into conveyor tunnel. Hi-vol = standard high volume air sampler; Hi-vol w/SSI = high volume air sampler equipped with Sierra 15 μmA size-selective inlet; Hi-vol w/cyclone and impactor = high volume air sampler equipped with Sierra Model 230CP cyclone precollector and Sierra Model 230 slotted cascade impactor.

[d] Total number of uncontrolled and controlled tests conducted.

[e] Data rated using criteria specified in Section 4.4.

[f] TP = Total Particulate; TSP = Total Suspended Particulate; IP = Inhalable Particulate.

[g] Located inside a building.

[h] No background samples collected during test program.

[i] Calculated from particulate concentrations in Table 24, page 92 of test report (Ref. No. 17).

6.5 OTHER PROCESS CONTROLS

There are a number of other techniques which can be used for the control of process sources where no substantive test data are available on control efficiency. These methods include both process and work practice modifications as well as housekeeping measures. Table 6-4 provides selected references which might be used to guide the reader in the application of these techniques.

TABLE 6-4. LITERATURE REFERENCES FOR PROCESS SOURCE CONTROLS WHERE NO TEST DATA ARE AVAILABLE

Control method	Literature reference(s)[a]
Process modifications	11, 18, 19, 20, 21, 22, 23
Work practice modifications	11, 18, 22, 23
Housekeeping	22

[a] Refers to references listed at the end of Section 6.

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SECTION 7
ESTIMATION OF CONTROL COSTS AND COST EFFECTIVENESS

Development and evaluation of particulate fugitive emissions control strategies require analyses of the relative costs of alternative control measures. Cost analyses are used by control agency personnel to develop overall strategies for an air pollution control district or to evaluate plant specific control strategies. Industry personnel perform cost analyses to evaluate control alternatives for a specific source or to develop a plant-wide emissions control strategy. Although the specifics of these analyses may vary depending upon the objective of the analysis and the availability of cost data, the general format is similar.

The primary goal of any cost analysis is to provide a consistent comparison of the real costs of alternative control measures. The objective of this section is to provide the reader with a methodology that will allow such a comparison. It will describe the overall structure of a cost analysis and provide the resources for conducting the analyses. Because cost data are continuously changing, specific cost data are not provided. However, sources of cost information and mechanisms for cost updating are provided.

The approach outlined in this section will focus on cost-effectiveness as the primary comparison tool. Cost-effectiveness is simply the ratio of the annualized cost of the emissions control to the amount of emissions reduction achieved. Mathematically, cost-effectiveness is defined by:

$$C^* = \frac{C_a}{\Delta R} \qquad (7\text{-}1)$$

where:

C^* = cost effectiveness ($/mass of emissions reduction)

C_a = annualized cost of the control measure ($/year)

ΔR = reduction (mass/year) in annual emissions

This general methodology was chosen because it is equally applicable to different controls that achieve equivalent emissions reduction on a single source and to measures that achieve varied reductions over multiple sources.

The discussion is divided into three sections. The first section describes the general cost analysis methodology, including the various types of costs that should be considered and presents methods for calculating those costs. The second identifies the primary cost elements associated with each of the fugitive emissions control systems identified in Section 4. The final section identifies sources of cost data and discusses methods for updating cost data to constant dollars.

7.1 GENERAL COST METHODOLOGY

Calculation of cost-effectiveness for comparison of control measures or control strategies can be accomplished in four steps. First, the alternative control/cost scenarios are selected. Second, the capital costs of each scenario is calculated. Third, the annualized costs for each of the alternatives is developed. Finally, the cost-effectiveness is calculated, taking into consideration the level of emissions reduction.

The general approach for performing each of the above steps is described below. This approach is intended to provide general guidance for cost comparison. It should not be viewed as a rigid procedure that must be followed in detail for all analyses. The reader may choose or may be forced through resource or informational constraints to omit some elements of the analysis. However, for comparisons to be valid, cautions that should be observed are: (1) All control scenarios should be treated in the same manner; and (2) cost elements that vary radically between cost scenarios should not be omitted.

7.1.1 Select Control/Cost Scenarios

Prior to the cost analysis general control measures or strategies will have been identified. These measures or strategies will fall into one of the major classes of fugitive emission control techniques that were identified in Tables 4-1 and 4-2. The first step in the cost analysis is to select a set of specific control/cost scenarios from the general techniques. The specific scenarios will include definition of the major cost elements and identification of specific implementation alternatives for each of the cost elements.

Each of the general control techniques identified in Chapter 4 has several major cost elements. These elements include capital equipment elements and operation/maintenance elements. For example, the major cost elements for chemical stabilization of an unpaved road include: (a) chemical acquisition; (b) chemical storage; (c) road preparation; (d) mixing the chemical with water; and (e) application of the chemical solution. The first step in any cost analysis is definition of these major cost elements. Information is provided in Section 7.2 on the major cost elements associated with each of the general techniques defined in Section 4.

For each major cost element, several implementation alternatives can be chosen. Options within each cost element include such choices as buying or renting equipment; shipping chemicals by railcar, truck tanker, or in drums via truck; alternative sources of power or other utilities; and use of plant personnel or contractors for construction and maintenance. The major cost elements and the implementation alternatives for each of these elements for the chemical stabilization example described above are outlined in Table 7-1.

7.1.2 Develop Capital Costs

The capital costs of a fugitive emissions control system are those direct and indirect expenses incurred up to the date when the control system is placed in operation. These capital costs include actual purchase expenses for capital equipment, labor and utility costs associated with installation of the control system, and system start-up and shakedown costs. In general, direct capital costs are the costs of control equipment and the labor, material, and utilities needed to install the equipment. Indirect costs are overall costs to the facility incurred by the system but not directly attributable to specific equipment items.

TABLE 7-1. IMPLEMENTATION ALTERNATIVES FOR STABILIZATION OF AN UNPAVED ROAD

Cost elements	Implementation alternatives
I. Purchase and ship chemical	A. Ship in railcar tanker (11,000-22,000 gal/tanker
	B. Ship in truck tanker (4,000-6,000 gal/tanker)
	C. Ship in drums via truck (55 gal/drum)
II. Store chemical	A. Store on plant property 1. In new storage tank 2. In existing storage tank a. Needs refurbishing b. Needs no refurbishing 3. In railcar tanker a. Own railcar b. Pay demurrage 4. In truck tanker a. Own truck b. Pay demurrage 5. In drums
	B. Store in contractor tanks
III. Prepare road	A. Use plant-owned grader to minimize ruts and low spots
	B. Rent contractor grader
	C. Perform no road preparation
IV. Mix chemical and water in application truck	A. Put chemical in spray truck 1. Pump chemical from storage tank or drums into application truck 2. Pour chemical from drums into application truck, generally using forklift
	B. Put water in application truck 1. Pump from river or lake 2. Take from city water line
V. Apply chemical solution via surface spraying	A. Use plant owned application truck
	B. Rent contractor application truck

Direct costs cover the purchase of equipment and auxiliaries and the costs of installation. These costs include system instrumentation and interconnection of the system. Capital costs also include any cost of site development necessitated by the control system. For example, if a fabric filter on a capture/collection system requires an access road for removal of the collected dust, this access road is included as a capital expense. The types of direct costs typically associated with fugitive emissions control systems include:

- Equipment costs
- Equipment installation
- Instrumentation
- Duct work
- Piping
- Electrical
- Site development
- Buildings
- Painting
- Insulation
- Structural support
- Foundations
- Supporting administrative structures
- Control panels
- Access roads or walkways

Indirect costs cover the expenses not attributable to specific equipment items. Items in this category are described below[1]:

1. Engineering costs - includes administrative, process, project, and general; design and related functions for specifications; bid analysis; special studies; cost analysis; accounting; reports; purchasing; procurement; travel expenses; living expenses; expediting; inspection; safety; communications; modeling; pilot plant studies; royalty payments during construction; training of plant personnel; field engineering; safety engineering; and consultant services.
2. Construction and field expenses - includes costs for temporary field offices; warehouses; craft sheds; fabrication shops; miscellaneous buildings; temporary utilities; temporary sanitary facilities; temporary roads; fences; parking lots; storage areas; field computer services; equipment fuel and lubricants; mobilization and demobilization; field office supplies; telephone and telegraph; time-clock system; field supervision; equipment rental; small tools; equipment repair; scaffolding; and freight.

3. Contractor's fee - includes costs for field-labor payroll; supervision field office; administrative personnel; travel expenses; permits; licenses; taxes; insurance; field overhead; legal liabilities; and labor relations.

4. Shakedown/startup - includes costs associated with system startup and shakedown.

5. Contingency costs - the excess account set up to deal with uncertainties in the cost estimate, including unforeseen escalation in prices, malfunctions, equipment design alterations, and similar sources.

The values for these items will vary depending on the specific operations to be controlled and the types of control systems used. Typical ranges for indirect costs based on the total installed cost of the capital equipment are shown in Table 7-2.

TABLE 7-2. TYPICAL VALUES FOR INDIRECT CAPITAL COSTS[1]

Cost item	Range of values
Engineering	8 to 20% of installed cost. High value for small projects; low value for large projects.
Construction and field expenses	7 to 70% of installed cost.
Contractor's fee	10 to 15% of installed cost.
Shakedown/startup	1 to 6% of installed cost.
Contingency	10 to 30% of total direct and indirect costs dependent upon accuracy of estimate. Generally, 20% is used in a study estimate.

7.1.3 Determine Annualized Costs

The most common basis for comparison of alternative control system is that of annualized cost. The annualized cost of a fugitive emission control system includes operating costs such as labor, materials, utilities, and maintenance items as well as the annualized cost of the capital equipment. The annualization of capital costs is a classical engineering economics problem, the solution of which takes into account the fact that money has time value. These annualized costs are dependent on the interest rate paid on borrowed money or collectable by the plant as interest (if available capital is used), the useful life of the equipment and depreciation rates of the equipment.

The components of the annualized cost of implementing a particular control technique are depicted graphically in Figure 7-1. Purchase and installation costs include freight, sales tax, and interest on borrowed money. The operation and maintenance costs reflect increasing frequency of repair as the equipment ages along with increased costs due to inflation for parts, energy, and labor. On the other hand, costs recovered by claiming tax credits or deductions are considered as income. Mathematically the annualized costs of control equipment can be calculated from:

$$C_a = CRF\ (C_p) + C_o + 0.5\ C_o \qquad (7\text{-}2)$$

where:

C_a = annualized costs of control equipment ($/year)

CRF = Capital Recovery Factor (1/year)

C_p = installed capital costs ($)

C_o = direct operating costs ($/year)

0.5 = plant overhead factor

The various components of this equation are briefly described below.

The annualized cost of capital equipment is calculated by using a capital recovery factor (CRF). The capital recovery factor combines interest on borrowed funds and depreciation into a single factor. It is a function of the interest rate and the overall life of the capital equipment and can be estimated by the following equation:

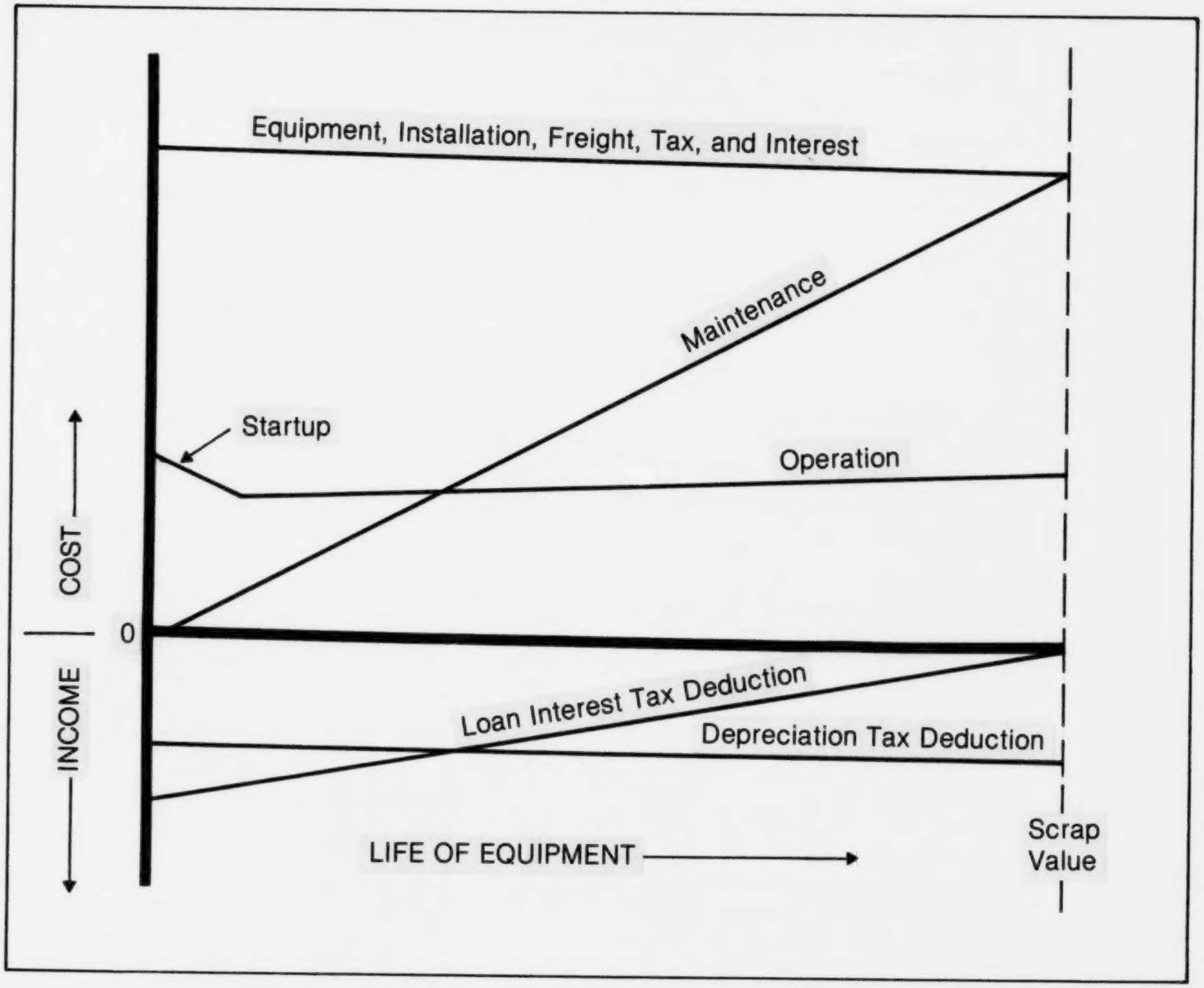

Figure 7-1. Graphical presentation of fugitive emission control costs

$$CRF = \frac{i(1 + i)^n}{(1 + i)^n - 1} \qquad (7\text{-}3)$$

where:

i = interest rate (annual % as a fraction)

n = economic life of the control system (year)

The other major components of the annualized cost are operation and maintenance costs (direct operating costs) and associated plant overhead costs. Operation and maintenance costs generally include labor, raw materials, utilities, and by-product costs or credits associated with day-to-day operation of the control system. Elements typically included in this category are[1]:

1. Utilities - includes water for process use and cooling; steam; electricity to operate controls, fans, motors, pumps, valves, and lighting; and fuel, if required.
2. Raw materials - includes any chemicals needed to operate the system.
3. Operating labor - includes supervision and the skilled and unskilled labor needed to operate, monitor, and control the system.
4. Maintenance and repairs - includes the manpower and materials to keep the system operating efficiently. The function of maintenance is both preventive and corrective, to keep down-time to a minimum.
5. By-product costs - in systems producing a salable product, this would be a credit for that product; in systems producing a product for disposal, this would be the cost of disposal.
6. Fuel costs - includes the incremental cost of the fuel, where more than the normal supply is used.

Another component of the operating cost is overhead, which is a business expense not charged directly to a particular part of the process but allocated to it. Overhead costs include administrative, safety, engineering, legal, and medical services; payroll, employee benefits; recreation;

and public relations. As suggested by Eq. 7-2, these charges are estimated to be approximately 50% of direct operating costs.

7.1.4 Calculate Cost Effectiveness

As discussed in the introduction to this section the most informative method for comparing control measures or control strategies for particulate fugitive emissions sources is on a cost-effectiveness basis. Mathematically, cost-effectiveness is defined as:

$$C^* = \frac{C_a}{\Delta R} \qquad (7\text{-}1)$$

where:

C^* = cost-effectiveness (\$/mass of emissions reduced)

C_a = annualized cost of control equipment (\$/year)

ΔR = annual reduction in particulate emissions (mass/year)

The annualized cost of control equipment can be calculated using Eq. 7-2. The annual reduction in particulate emissions can be calculated from the following equation:

$$\Delta R = M\ e\ c \qquad (7\text{-}4)$$

where:

M = annual source extent

e = uncontrolled emission factor (i.e., mass of uncontrolled emissions per unit of source extent)

c = average control efficiency expressed as a fraction

The methodology for calculating annualized costs and sources of data on costs of fugitive emissions control systems are contained in this section. Information relative to uncontrolled emission factors is discussed in Section 3 and estimates of control efficiencies for various control systems are presented in Sections 5 and 6.

7.2 COST ELEMENTS OF FUGITIVE EMISSIONS CONTROL SYSTEMS

The cost methodology outlined in Section 7.1 requires that the analyst define and select alternative control/cost scenarios and develop costs for the major cost elements within these scenarios. The objective of this subsection is to assist the reader in identifying the implementation alternatives and major cost elements associated with the emission reduction techniques identified in Section 4. For open dust sources, the control techniques addressed are: wet dust suppression; surface cleaning; and paving. For process fugitive sources, the primary control techniques addressed are: wet suppression; capture/collection; and plume aftertreatment.

Implementation alternatives for open dust source emission control measures are presented in Tables 7-3 through 7-5. Table 7-3 presents implementation alternatives for water and chemical dust suppressant systems. Table 7-4 presents alternatives for three types of street cleaning systems--sweeping, flushing, and a combination of flushing and broom sweeping. Table 7-5 presents alternatives for streets or parking lot paving.

Implementation alternatives for process fugitive source control measures are presented in Tables 7-6 through 7-8. Table 7-6 outlines alternatives for wet suppression systems. Table 7-7 presents alternatives for a capture/collection system; these alternatives are applicable for active enclosures, capture hoods, and receiving hoods. Table 7-8 presents implementation alternatives for plume aftertreatment systems.

After the control scenarios are selected, the analyst must estimate the capital cost of the installed system and the operating and maintenance costs. The indirect capital costs elements are common to all systems and were identified in Table 7-2. The direct capital cost elements and direct operation and maintenance cost elements which are unique to each type of fugitive emission control system are identified in Tables 7-9 through 7-14. These costs are provided for dust suppressant programs for open dust sources in Table 7-9, street cleaning programs in Table 7-10, paving in Table 7-11, wet suppression systems for process sources in Table 7-12, capture/collection systems in Table 7-13, and plume aftertreatment systems in Table 7-14.

TABLE 7-3. IMPLEMENTATION ALTERNATIVES FOR DUST SUPPRESSANTS APPLIED TO AN UNPAVED ROAD

Program implementation alternative	Dust suppressant type	
	Chemicals	Water
I. Purchase and ship dust suppressant		
A. Ship in railcar tanker (11,000-22,000 gal/tanker)	X	
B. Ship in truck tanker (4,000-6,000 gal/tanker)	X	
C. Ship in drums via truck (55 gal/drum)	X	
II. Store dust suppressant		
A. Store on plant property		
1. In new storage tank	X	
2. In existing storage tank		
a. Needs refurbishing	X	
b. Needs no refurbishing	X	
3. In railcar tanker		
a. Own railcar	X	
b. Pay demurrage	X	
4. In truck tanker		
a. Own truck	X	
b. Pay demurrage	X	
5. In drums	X	
B. Store in contractor tanks	X	
III. Prepare road		
A. Use plant-owned grader to minimize ruts and low spots	X	X
B. Rent contractor grader	X	X
C. Perform no road preparation	X	X
IV. Mix dust suppressant/water in application truck		
A. Put suppressant in spray truck		
1. Pump suppressant from storage tank or drums into application truck	X	
2. Pour suppressant from drums into application truck, generally using forklift	X	
B. Put water in application truck		
1. Pump from river or lake	X	X
2. Take from city water line	X	X
V. Apply suppressant solution via surface spraying		
A. Use plant owned application truck	X	X
B. Rent contractor application truck	X	X

TABLE 7-4. IMPLEMENTATION ALTERNATIVES FOR STREET CLEANING

Program implementation alternative	Broom-sweeping	Flushing	Flushing and broom-sweeping
I. Acquire flusher and driver			
A. Purchase flusher and use plant driver		X	X
B. Rent flusher and driver		X	X
C. Use existing unpaved road watering truck		X	X
II. Acquire broom sweeper and driver			
A. Purchase broom sweeper and use plant driver	X		X
B. Rent broom sweeper and driver	X		X
III. Fill flusher tank with water			
A. Pump water from river or lake		X	X
B. Take water from city line		X	X
IV. Maintain purchased flusher		X	X
V. Maintain purchased broom sweeper	X		X

TABLE 7-5. IMPLEMENTATION ALTERNATIVES FOR PAVING

Program implementation alternative
I. Excavate existing surface to make way for base and surface courses
A. 2-in. depth
B. 4-in. depth
C. 6-in. depth
II. Fine grade and compact subgrade
III. Lay and compact crushed stone base course
A. 2-in. depth
B. 4-in. depth
C. 6-in. depth
IV. Lay and compact hot mix asphalt (probably AC120-150) surface course
A. 2-in. depth
B. 4-in. depth
C. 6-in. depth

TABLE 7-6. IMPLEMENTATION ALTERNATIVES FOR WET SUPPRESSION

I. Basic design decisions

  A. What type wet suppression system will be used?
    - Water spray
    - Water/surfactant spray
    - Micron-sized foam
    - Combination system

  B. What sources will be controlled?

  C. What system layout will be used?
    - Centralized supply with headers for each source
    - Individual systems for some sources

II. Construction/installation decisions

  A. Who will install system?
    - Contractor
    - Plant personnel

III. Operational decisions

  A. What is the water source?
    - Plant wells
    - Local surface waters
    - City water system

  B. Under what weather conditions will the system be needed?
    - Above freezing only
    - Below freezing

  C. How will routine maintenance be provided?
    - Plant personnel
    - Maintenance contractor

TABLE 7-7. IMPLEMENTATION ALTERNATIVES FOR CAPTURE/COLLECTION SYSTEMS

I. Basic design decisions

  A. What type hooding system best fits each source?
    - Enclosure
    - Capture hood
    - Receiving hood

  B. What type of air pollution control device best meets plant needs?
    - Cyclone
    - Wet scrubber
    - Fabric filter

  C. How will collected particulate be handled?
    - Screw conveyor
    - Pneumatic transport
    - Slurry piping
    - Batch removal

  D. What system layout will be used?
    - Multiple collection points ducted to centralized air pollution control device
    - Dedicated air pollution control devices for each source
    - Mixed system

  E. Who will design the system?
    - Outside design of total system
    - Plant design of system with vendor design of individual components

II. Construction/installation

  A. Who will install system?
    - Plant personnel
    - Contractor

  B. Who is responsible for system shakedown/startup?
    - Plant environmental staff
    - Plant operators
    - Contractor personnel

III. Operational decisions (dependent on type of system selected)

  A. What electrical source will be used?
    - Public utility
    - Plant power system

  B. What water source will be used?
    - Plant well
    - Local surface water
    - Public water system

  C. How will routine maintenance be provided?
    - Plant personnel
    - Outside contractor

  D. How will collected particulate be disposed?
    - Returned to process
    - Landfilled
    - Surface impoundment

TABLE 7-8. IMPLEMENTATION ALTERNATIVES FOR PLUME AFTERTREATMENT SYSTEMS

I. Basic design decisions

  A. What sources are to be controlled?

  B. What is the physical size of the source and resulting dust plume?

  C. Is the area sheltered from wind or cross drafts such that aftertreatment can be effectively applied?

  D. How many foggers or nozzles are to be used and where are they to be positioned?

  E. How will water and electric power be supplied to unit(s)?
  - Central system
  - Separate line(s) from multiple sources

II. Construction/installation decisions

  A. Who will install system?
  - Contractor
  - Plant personnel

III. Operational decisions

  A. What is the water source?
  - Plant wells
  - Local surface waters
  - City water system

  B. What electrical source will be used?
  - Public utility
  - Plant power

  C. Under what weather conditions will the system be needed?
  - Above freezing only
  - Below freezing

  D. How will routine maintenance be provided?
  - Plant personnel
  - Maintenance contractor

TABLE 7-9. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR DUST SUPPRESSANT SYSTEMS[a] (OPEN SOURCES)

Capital equipment

- Storage equipment
  - Tanks
  - Railcar
  - Pumps
  - Piping

- Application equipment
  - Trucks
  - Spray system
  - Piping (including winterizing)

O&M expenditures

- Utility or fuel costs
  - Water
  - Electricity
  - Gasoline or diesel fuel

- Supplies
  - Chemicals
  - Repair parts

- Labor
  - Application time
  - Road conditioning
  - System maintenance

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[a] Not all items are necessary for all systems. Specific items are dependent on the control scenario selected.

TABLE 7-10. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR STREET CLEANING

Capital equipment

- Sweeping
  - Broom
  - Vacuum system
- Flushing
  - Piping
  - Flushing truck
  - Water pumps

O&M expenditures

- Utility and fuel costs
  - Water
  - Gasoline or diesel fuel
- Supplies
  - Replacement brushes
- Labor
  - Sweeping or flushing operation
  - Truck maintenance
- Waste disposal

TABLE 7-11. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR PAVING

Capital equipment

- Operating equipment
  - Graders
  - Paving application equipment
  - Materials
  - Paving material (asphalt or concrete)
  - Base material

O&M expenditures

- Supplies
  - Patching material
- Labor
  - Surface preparation
  - Paving
  - Road maintenance
  - Equipment maintenance

TABLE 7-12. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR WET SUPPRESSION SYSTEMS (PROCESS SOURCES)

Capital equipment

- Water spray systems
  - Supply pumps
  - Nozzles
  - Piping (including winterization)
  - Control system
  - Filtering units

- Water/surfactant and foam systems only
  - Air compressor
  - Mixing tank
  - Metering or proportioning unit
  - Surfactant storage area

O&M expenditures

- Utility costs
  - Water
  - Electricity

- Supplies
  - Surfactant
  - Screens

- Labor
  - Maintenance
  - Operation

TABLE 7-13. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR CAPTURE COLLECTION SYSTEMS[a]

Capital equipment

- Dust collector
  - Baghouse or scrubber
  - Concrete work
  - Dust removal system
  - Control instrumentation
  - Monitoring instrumentation
- Hood(s)
- Ventilation system
  - Fan
  - Electrical wiring
  - Ductwork
  - Concrete support work
  - Damper system
  - Expansion joints
- Dust storage system

O&M expenditures

- Utilities
  - Electricity
  - Water
- Supplies
  - Replacement bags
  - Fan motors
  - Chemical additives for scrubber
- Labor
  - System operation
  - Control device maintenance and cleaning
  - Ductwork maintenance
- Disposal of collected particulate

---

[a] Specific items included will depend on the control scenario selected.

TABLE 7-14. CAPITAL AND O&M EXPENDITURES FOR PLUME AFTERTREATMENT SYSTEMS

Capital equipment:

- Fogging or spray heads (nonelectrostatic)
    - Atomizers
    - Supply pumps
    - Plumbing (including weatherization)
    - Water filters
    - Flow control system

- Electrostatic foggers or spray nozzles
    - Atomizer(s) and high voltage power supply
    - Water pumps and plumbing (including weatherization)
    - Water filters
    - Flow control system
    - Power lines and electric utilities

O&M expenditures:

- Utility costs
    - Water
    - Electricity

- Supplies
    - Antifreeze agent(s)
    - Screens
    - Replacement electrodes (if applicable)

- Labor
    - Operation
    - Maintenance

7.3 SOURCES OF COST DATA

Collection of the data to conduct a cost analysis can sometimes be difficult. If a well defined system is being costed, the best sources of accurate capital costs are vendor estimates. However, if the system is not sufficiently defined to develop vendor estimates, published cost data can be used. Table 7-15 presents sources of cost data for both open dust and process fugitive emissions control systems. The first three items relate primarily to open dust control systems while the last three references can be used to estimate component costs for both open dust and process fugitive emissions control systems.

Often published cost estimates are based on different time-valued dollars. These estimates must be adjusted for inflation so that they reflect the most probable capital investments for a current time and can be consistently compared. Capital cost indices are the techniques used for updating costs. These indices provide a general method for updating overall costs without having to complete in-depth studies of individual cost elements. Indices that typically are used for updating control system costs are the Chemical Engineering Plant Cost Index, the Bureau of Labor Statistics Metal Fabrication Index, and the Commerce Department Monthly Labor Review.

Operation and maintenance cost estimates typically are based on vendor or industry experience with similar systems. In the absence of such data, rough estimates can be developed from sources 3 and 6 in Table 7-15.

REFERENCES FOR SECTION 7

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TABLE 7-15. PUBLISHED SOURCES OF FUGITIVE EMISSION CONTROL SYSTEM COST DATA

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SECTION 8
FUGITIVE EMISSIONS CONTROL STRATEGY DEVELOPMENT

As outlined in the previous sections, development of a fugitive emissions control strategy for an industrial facility can be accomplished through a five step process. These five steps are:

Step 1: Identify and classify all fugitive sources.

Step 2: Prepare an emissions inventory.

Step 3: Identify control alternatives.

Step 4: Estimate control system performance.

Step 5: Estimate control costs and cost-effectiveness.

This section will illustrate those five steps for a hypothetical 300-ton/hr rock crushing plant. As shown in Figure 8-1, the facility includes a primary, secondary, and tertiary crusher, and associated materials sizing, handling, and storage facilities. The following subsections describe the control strategy evalution for this facility.

8.1 IDENTIFY/CLASSIFY FUGITIVE EMISSION SOURCES

The fugitive particulate emission sources for this facility are identified schematically in Figure 8-1. They include:

- A primary crusher;
- A secondary crusher;
- A tertiary crusher;
- Two screens;

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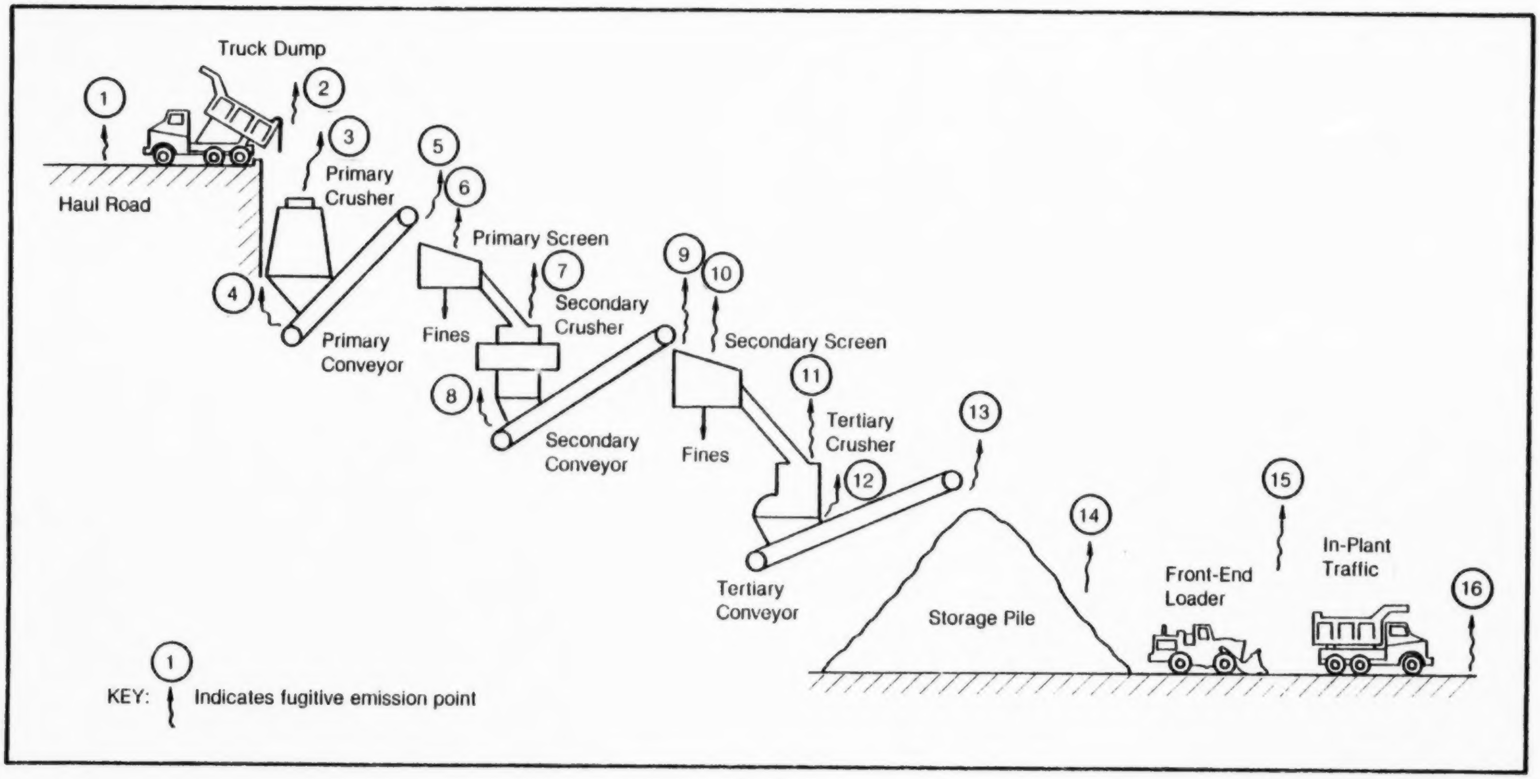
Truck Dump
1
2
3
Haul Road
Primary
Crusher
4
Primary
Conveyor
5
6
Primary Screen
Fines
7
Secondary
Crusher
8
Secondary
Conveyor
9
10
Secondary Screen
Fines
11
Tertiary
Crusher
12
Tertiary
Conveyor
13
Storage Pile
14
Front-End
Loader
15
In-Plant
Traffic
16
KEY: 1 Indicates fugitive emission point

Figure 8-1. Simplified process flow diagram for a typical rock crushing plant

- A truck dump station;
- Six conveyor transfer points;
- Vehicular traffic on unpaved haul road between the quarry and the plant;
- Windblown emissions from product storage;
- A front-end loader for loadout of customer trucks; and
- Vehicular traffic on a paved road between the loadout area and the property line.

These sources are consistent with those identified for the minerals products industry in Table 2-1 and the general open dust sources in Table 2-2.

8.2 PREPARE EMISSIONS INVENTORY

Calculation of the estimated emission rate for a given source requires data on source extent, uncontrolled emission factor, and control efficiency. The mathematical expression for this calculation is as follows:

$$R = M\,e\,(1 - c) \tag{8-1}$$

where:

R = estimated mass emission rate

M = source extent

e = uncontrolled emission factor (i.e., mass of uncontrolled emissions per unit of source extent)

c = fractional efficiency of control

For this plant we assume that the initial control efficiency for all sources is 0%. The uncontrolled emission factors for the five open dust sources and the 11 process sources as well as the required source extents are presented below.

8.2.1 Unpaved Haul Road

The uncontrolled emission factor for unpaved roads as presented in Reference 1 is:

$$e = k(5.9) \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right) \quad \text{(lb/VMT)} \qquad (8\text{-}2)$$

where:

k = particle size multiplier (dimensionless)

s = silt content of road surface material (%)

S = mean vehicle speed (mph)

W = mean vehicle weight (tons)

w = mean number of wheels

p = number of days with at least 0.01 in. of precipitation per year

Plant data required to calculate the emission factor are silt content, vehicle speed, mean vehicle weight, and mean number of wheels. These are taken from the hypothetical plant data presented in Table 8-1.

Using the particle size multiplier for TSP and precipitation frequency from Reference 1, the resultant emission factor for the haul road is:

$$e = 0.8(5.9) \left(\frac{7.3}{12}\right) \left(\frac{20}{30}\right) \left(\frac{40}{3}\right)^{0.7} \left(\frac{6}{4}\right)^{0.5} \left(\frac{365-140}{365}\right)$$

$$= 8.86 \text{ lb/VMT}$$

where:

k = 0.80 for particles $\leqq$ 30 μmA (see Reference 1)

s = 7.3% (given in Table 8-1)

S = 20 mph (given in Table 8-1)

W = 40 tons (given in Table 8-1)

w = 6 (given in Table 8-1)

p = 140 (see Reference 1, as applied to lower Great Lakes)

TABLE 8-1. PLANT AND PROCESS DATA FOR HYPOTHETICAL FACILITY

PROCESS OPERATION -
Operating rate: 150 ton/hr
Operating hours: 1,920 hr/yr

HAUL ROAD -
Average daily traffic = 100 vehicles/day[a]
Average vehicle weight = 40 tons
Average number of vehicle wheels = 6
Average vehicle speed = 20 mph
Roadway length = 6.3 miles
Roadway width = 30 ft
Roadway silt content = 7.3%

TRUCK DUMP -
Material silt content = 0.5%
Mean wind speed = 5 mph
Drop height = 10 ft
Material moisture content = 2%
Average truck capacity = 16 yd^3

STORAGE PILE -
Storage pile silt content = 2.2%
Storage pile size = 0.5 acre

FRONT-END LOADER -
Aggregate silt content = 1.6%
Mean wind speed = 5 mph
Drop height = 5 ft
Aggregate moisture content = 2%
Loader dumping capacity = 3 yd^3

CUSTOMER TRAFFIC -
Road augmentation factor = 1
No. of travel lanes = 2
Surface silt content = 6%
Surface dust loading = 1,000 lb/mile
Average vehicle weight = 30 tons[c]
Roadway length = 0.5 miles
Average daily traffic = 120 vehicles/day[d]

---

[a] 50 round trips per day.

[b] Tare + load ÷ 2 = 28 + 24/2 = 40 tons.

[c] Tare + load ÷ 2 = 20 + 20/2 = 30 tons.

[d] 60 round trips per day.

8.2.2 Truck Dumping

The truck dump can be considered as a batch drop operation. Thus, the uncontrolled emission factor from Reference 1 is:

$$e = k(0.0018)\ \frac{\left(\frac{s}{5}\right)\ \left(\frac{U}{5}\right)\ \left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^{2}\ \left(\frac{Y}{6}\right)^{0.33}}\ \text{(lb/ton)} \qquad (8\text{-}3)$$

where:

k = particle size multiplier (dimensionless)

s = material silt content (%)

U = mean wind speed (mph)

H = drop height (ft)

M = material moisture content (%)

Y = dumping device capacity (yd^3)

Using the multiplier for TSP and the data shown in Table 8-1, the uncontrolled emission factor for the truck dump would be:

$$e = 0.77\ (0.0018)\ \frac{\left(\frac{0.5}{5}\right)\ \left(\frac{5}{5}\right)\ \left(\frac{10}{5}\right)}{\left(\frac{2}{2}\right)^{2}\ \left(\frac{16}{6}\right)^{0.33}}$$

$$= 0.00020\ \text{lb/ton}$$

where:

k = 0.77 for particles $\leqq$ 30 μmA (see Reference 1)

s = 0.5% (given in Table 8-1)

U = 5 mph (given in Table 8-1)

H = 10 ft (given in Table 8-1)

M = 2% (given in Table 8-1)

Y = 16 yd^3 (given in Table 8-1)

8.2.3 Storage Pile

The TSP emission factor for wind erosion from storage piles as given in Reference 1 is:

$$e = 1.7 \left(\frac{s}{1.5}\right) \left(\frac{365-p}{235}\right) \left(\frac{f}{15}\right) \text{ (lb/acre/day)} \qquad (8\text{-}4)$$

where:

s = silt content (%)

p = number of days with $\geqq$ 0.01 in. of precipitation per year

f = percentage of time the unobstructed wind speed exceeds 12 mph

Using the data on silt content and estimates of p and f from Reference 1, the resultant TSP emission factor is:

$$e = 1.7 \left(\frac{2.2}{1.5}\right) \left(\frac{365-140}{235}\right) \left(\frac{20}{15}\right)$$

$$= 3.2 \text{ lb/acre/day}$$

where:

s = 2.2% (Table 8-1)

p = 140 (Reference 1)

f = 20 (estimate)

8.2.4 Front-End Loader

For operation of the front-end loader, the appropriate uncontrolled emission factor presented in Reference 1 is:

$$e = k(0.0018) \frac{\left(\frac{s}{5}\right) \left(\frac{U}{5}\right) \left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^{2} \left(\frac{Y}{6}\right)^{0.33}} \qquad (8\text{-}5)$$

where:

k = particle size multiplier (dimensionless) s = material silt content (%)

U = mean wind speed (mph)

H = drop height (ft)

M = material moisture content (%)

Y = dumping device capacity (yd^3)

Again, using the particle size multiplier for TSP and the operational information provided in Table 8-1, the applicable emission factor is:

$$e = 0.73\ (0.0018)\ \frac{\left(\frac{1.6}{5}\right)\ \left(\frac{5}{5}\right)\ \left(\frac{5}{5}\right)}{\left(\frac{2}{2}\right)^{2}\ \left(\frac{3}{6}\right)^{0.33}}$$

$$= 0.000529\ \text{lb/ton}$$

where:

k = 0.73 for particles ≦ 30 μmA (see Reference 1)

s = 1.6% (see Table 11.2.3-1 of Reference 1 for crushed limestone)

U = 5 mph (given in Table 8-1)

H = 5 ft (given in Table 8-1)

M = 2% (given in Table 8-1)

Y = 3 yd^3 (given in Table 8-1)

8.2.5 Customer Traffic

Finally, for customer traffic in the plant, the uncontrolled emission factor for industrial paved roads provided in Reference 1 is:

$$e = k(0.090)I\ \left(\frac{4}{n}\right)\ \left(\frac{s}{10}\right)\ \left(\frac{L}{1,000}\right)\ \left(\frac{W}{3}\right)^{0.7} \qquad (8\text{-}6)$$

where:

k = particle size multiplier (dimensionless)

I = industrial augmentation factor (dimensionless)

n = number of traffic lanes (dimensionless)

s = surface material silt content (%)

L = surface dust loading (lb/mile)

W = average vehicle weight (tons)

From the data shown in Table 8-1, the emission factor for TSP would be:

$$e = 0.86\ (0.090)\ (1) \left(\frac{4}{2}\right) \left(\frac{6}{10}\right) \left(\frac{1{,}000}{1{,}000}\right) \left(\frac{30}{3}\right)^{0.7}$$

$$= 0.466 \text{ lb/VMT}$$

where:

k = 0.86 for particles ≦ 30 μmA (see Reference 1)

I = 1 for all vehicles traveling on paved surfaces (see Reference 1, p. 11.2.6-2)

n = 2 (given in Table 8-1)

s = 6% (given in Table 8-1)

L = 1,000 lb/mile (given in Table 8-1)

W = 30 tons (given in Table 8-1)

8.2.6 Process Sources

The emission factors for the process sources, based on data in Reference 1, are:

Primary crushing:	0.28 lb/ton
Secondary crushing:	0.28 lb/ton
Tertiary crushing:	1.85 lb/ton
Screening:	0.16 lb/ton/screen
Conveyor transfer:	0.0034 lb/ton/transfer point

8.2.7 Source Extents

The data in Table 8-1 can be used to calculate the following source extents:

- Haul road traffic:

$$M = 240\ \frac{\text{days}}{\text{yr}} \times 100\ \frac{\text{vehicles}}{\text{day}} \times 6.3\ \frac{\text{miles}}{\text{vehicle}} = 151{,}000\ \text{VMT/yr}$$

- Truck dump:

$$M = 50\ \frac{\text{trips}}{\text{day}} \times 240\ \frac{\text{days}}{\text{yr}} \times 24\ \frac{\text{tons}}{\text{trip}} = 288{,}000\ \frac{\text{tons}}{\text{yr}}$$

- Storage piles:

$$\begin{aligned} M &= 0.5\ \text{acre} \times 365\ \text{day/yr} \\ &= 182\ \text{acre day/yr} \end{aligned}$$

- Front-end loader:

$$M = 60\ \frac{\text{vehicles}}{\text{day}} \times 240\ \frac{\text{days}}{\text{yr}} \times 20\ \frac{\text{tons}}{\text{vehicle}} = 288{,}000\ \frac{\text{tons}}{\text{yr}}$$

- In-plant traffic:

$$M = 120\ \frac{\text{vehicles}}{\text{day}} \times 240\ \frac{\text{days}}{\text{yr}} \times 0.5\ \frac{\text{miles}}{\text{vehicle}} = 14{,}400\ \frac{\text{VMT}}{\text{yr}}$$

- Process sources:

$$\begin{aligned} M &= 150\ \text{tons/hr} \times 1{,}920\ \text{hr/yr} \\ &= 288{,}000\ \text{tons/yr} \end{aligned}$$

8.2.8 Total Plant Emissions

The above data on source extents and emission factors can be substituted into Eq. 8-1 to obtain the following emissions inventory for the hypothetical plant:

Source	TSP emissions (tons/year)
Haul road traffic	669
Truck dump	0.029
Storage pile erosion	0.29
Front loader	0.076
Customer traffic	3
Primary crushing	40
Secondary crushing	40
Tertiary crushing	266
Screens	46
Transfers	3
TOTAL	1,067

8.3 IDENTIFY CONTROL ALTERNATIVES

Based on the above emissions inventory, the primary focus of control should be vehicular traffic and certain process fugitive sources (primarily secondary and tertiary crushing and screening operations). The information in Tables 4-1 and 4-2 can be used to assist in identifying control alternatives.

Table 4-1 suggests that three methods can be used to control emissions from unpaved roads--wet suppression, chemical stabilization, and physical stabilization. For this hypothetical example, chemical stabilization was selected as the most feasible means. Wet suppression was rejected because of the difficulty in maintaining watering systems over relatively long stretches of roads in rural areas. Chemical rather than physical stabilization was selected because of the temporary nature of the facility.

The two principal means of controlling emissions from crushing and screening operations are wet suppression and capture hoods with an associated air pollution control device. Wet suppression was selected as the preferred control because of difficulties associated with the operation and maintenance of capture/collection systems on mobile crushed stone facilities.

8.4 ESTIMATE CONTROL EFFICIENCIES

Based on available performance data, a petroleum based resin was selected for chemical dust suppression on the unpaved road. The data in Table 5-2 suggest that control efficiencies of about 90% can be achieved over short to moderate duration with such vehicles. In fact, an average TSP control efficiency of 90% can be achieved for up to about 5,000 vehicle passes.

Only limited test data are available on the effectiveness of wet suppression systems in controlling emissions from minerals processing operations. The data in Table 6-2 indicate that control efficiencies for crushing operations range from 27% to about 90%. Available data suggest that the finer the crushing operation, the lower the efficiency. No control efficiencies are specified for screens, but those controls should be at least as effective as controls for tertiary crushers. Based on these limited data, the control efficiency estimates are:

Primary crusher: 80%

Secondary crusher: 65%

Tertiary crusher: 50%

Screens: 50%

8.5 CALCULATE COST AND COST EFFECTIVENESS

8.5.1 Chemical Stabilization of Unpaved Roads

The procedure for calculating the estimated cost and the associated cost effectiveness of controlling vehicular emissions by chemical stabilization of the unpaved haul road at the hypothetical plant is as follows.

Step 1 - Determine the Times Between Applications and the Application Intensity

The vehicle and road characteristics listed in Table 8-1 are similar to those in the footnotes of Table 2-1 of Reference 2. The following application parameters are taken from Table 2-1 of Reference 2:

Initial application intensity = 0.83 gal. of 20% solution/yd^2

Reapplication intensity = 1.0 gal. of 12% solution/yd^2

Application frequency = once every 55 days

Step 2 - Calculate the Number of Annual Applications Necessary and Number of Treated Miles

$$\text{No. of annual applications} = \frac{365 \text{ days/yr}}{55 \text{ days/application}}$$

$$= 6.64 \text{ applications/yr}$$

$$\text{No. of treated miles per year} = 6.3 \, \frac{\text{miles}}{\text{application}} \times 6.64 \, \frac{\text{applications}}{\text{year}}$$

$$= 42 \text{ treated miles/year}$$

Step 3 - Select the Desired Program Implementation Plan

The decision is made to purchase rather than rent equipment. The implementation plan and associated costs are outlined in Table 8-2, Scenario 2.

Step 4 - Calculate Total Annual Cost

To annualize the capital investment, the capital cost shown in Table 8-2, Scenario 2, is simply multiplied by a capital recovery factor which is calculated as follows:

$$CRF = [i(1 + i)^n] / [(1 + i)^n - 1]$$

where:

i = annual interest rate fraction

n = number of payment years

Assuming $i = 0.15$ and $n = 10$ years,

$$CRF = \frac{0.15\ (1.15)^{10}}{(1.15)^{10} - 1} = 0.199$$

The annual operation and maintenance costs (C_o) are calculated as follows:

$$C_o = \$4,785/\text{treated mile} \times 42\ \text{treated miles/year} + \$630/\text{actual mile} \times 6.3\ \frac{\text{actual miles}}{\text{year}}$$

$$= \$205,000/\text{year}$$

The total annualized cost (C_a) is:

$$C_a = CRF\ (C_p) + C_o + 0.5(C_o)$$

$$= (0.199)\ (105,000) + 205,000 + 0.5\ (205,000)$$

$$= \$328,000$$

Because the costs in Table 8-2 are based on a road width of 40 ft, it is necessary to scale total cost by actual road width of 30 ft:

$$\text{Actual total annualized cost} = \$328,000/\text{year} \times \frac{30\ \text{ft}}{40\ \text{ft}}$$

$$= \$246,000/\text{year}$$

TABLE 8-2. COST COMPARISON FOR TWO SELECTED IMPLEMENTATION SCENARIOS

Alternative approach	Cost Capital investment ($)	Unit O&M cost[a] $/Treated mile	$/Actual mile
Scenario 1 - Rent where possible to minimize capital expenditure			
1. Purchase chemical and ship in truck tanker		4,650	
2. Store in contractor tank		140	
3. Rent contractor grader to prepare road			1,200
4. Take water from city line		20	
5. Rent contractor truck (includes labor to pump water and chemical and apply solution)		500	
	0	5,310	1,200
Scenario 2 - Buy equipment where possible			
1. Purchase chemical and ship in truck tanker		4,650	
2. Store in newly purchased storage tank	30,000		
3. Prepare road with plant owned grader			630
4. Pump water from river or lake	5,000	135	
5. Apply chemical with plant owned application truck (includes labor to pump water and chemical and apply solution)	70,000		
	105,000	4,785	630

[a] Plant overhead costs are included.

Step 5 - Calculate Cost-Effectiveness (C*)

Cost-effectiveness is defined as:

$$C^* = \frac{C_a}{\Delta R}$$

where:

C_a = total cost from Step 4

ΔR = reduction in TSP emissions; i.e., the product of the uncontrolled emission rate and the fractional efficiency of control

$$C^* = \frac{\$246{,}000/\text{year}}{669\ \text{ton/year} \times 0.9}$$

= \$409/ton of TSP emissions reduced by chemical stabilization of unpaved roads

8.5.2 Wet Suppression of Crushing and Screening Operations

The procedure for calculating the estimated cost and cost-effectiveness of wet suppression applied to materials handling at the hypothetical plant is as follows:

Step 1 - Select the Desired Program Implementation Plan

The elements of the program implementation plan are as follows:

1. Sprays are used at one primary, one secondary, and one tertiary crusher, the truck dump to the primary crusher, two screens, and six conveyor transfer points.
2. A centralized system with an industrial water supply is used.
3. Winterizing equipment is required.
4. The process operates 40 hr/week, 48 weeks/year, and because of operating conditions, the control equipment is operated 80% of the time that the process operates.

Step 2 - Calculate Capital Costs

The capital costs (C_p) are summarized as follows:

Type of equipment	Equipment cost ($)	Installation cost ($)	Total cost ($)
Wet suppression system	24,520	33,830	58,350
Water filter and flush	2,970	350	3,320
High pressure system for truck dump	4,630	2,290	6,920
Shelter house	4,280	640	4,920
Winterization	3,640	3,710	7,350
Total	40,040	40,820	80,860

Reference 3 was the basis for capital costs. These costs are updated from July 1974 to January 1984 using the CE Plant Cost Index for Fabricated Equipment. The winterization cost was estimated as 10% of other capital equipment.

Step 3 - Calculate Annual Operating Costs

There are four categories of operating costs (C_o):

1. Utilities

   Electrical power - 2,880 kWh/year @ 5.5¢/kWh = $ 160
   Water - 690,000 gal/year @ 10¢/100 gal. = 690

2. Maintenance

   Labor - 192 hr/year @ $10/hr = 1,920
   Materials = 1,850

3. Operation

   Labor - 96 hr/year at $10/hr = 960
   Surfactant 690 gal/year @ $6/gal = 4,140

4. Overhead

   Payroll (35% of labor) = 1,010
   Office/general (40% of maintenance and operations) = 3,620

Total operating costs $14,350

Plant overhead costs are included in this value. Reference 3 was the basis for the units of operating materials, utilities and labor. The estimated average cost of electrical power for industrial users as of January 1984 was based on Energy Users. The unit cost for water was an MRI estimate. The estimated hourly rate for a laborer in the minerals manufacturing industry in January 1984 was based on statistics in the Monthly Labor Review. Surfactant costs were updated from July 1974 to January 1984 using the CE Plant Cost Index for Pipes, Valves, and Fittings.

Step 4 - Calculate Annualized Cost

The capital recovery factor is given by:

$$CRF = [i(1+i)^n] / [(1+i)^n-1]$$

where:

i = annual interest rate

n = effective life

Assuming $i = 0.15$ and $n = 10$ years,

$$CRF = 0.199252$$

The annualized costs (C_a) are calculated as follows:

$$C_a = CRF\ (C_p) + C_o + 0.5(C_o)$$

where:

C_p = Capital investment ($)

CRF = Capital recovery factor

C_o = Annual operating costs ($/yr)

Substituting the cost values obtained from Steps 2 and 3,

$$C_a = 80{,}860\ (0.199252) + 14{,}350 + 0.5\ (14{,}350)$$

$$= \$37{,}600/\text{year}$$

Step 5 - Calculate Cost-Effectiveness

Cost-effectiveness is defined as:

$$C^* = \frac{C_a}{\Delta R}$$

where:

C_a = total cost from Step 4

ΔR = reduction in TSP emissions; i.e., the product of uncontrolled emission rate and the fractional efficiency of control

The calculated emissions reductions are as follows:

Primary crusher: (40 tons/yr)(0.80) = 32
Secondary crusher: (40 tons/yr)(0.65) = 26
Tertiary crusher: (266 tons/yr)(0.5) = 133
Screens: (46 tons/yr)(0.5) = 23
Total = 214 tons/year

$$C^* = \frac{\$37{,}600/\text{year}}{214\ \text{tons/year}} = \$176/\text{ton of TSP reduced by wet suppression of crushing and screening operations}$$

8.5.3 Plant Control Costs and Cost Effectiveness

The two control measures that were considered for the theoretical plant are summarized below with their respective costs:

Control measure	Annualized costs ($)	Cost effectiveness ($/ton)
Chemical stabilization of unpaved roads	246,000	409
Wet suppression of crushing and screening operations	37,600	176

With the implementation of these two control measures, total TSP emissions from this hypothetical plant would be reduced from 1,067 tons/year to 251 tons/year.

REFERENCES FOR SECTION 8

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APPENDIX A
ESTIMATION OF AIR QUALITY IMPACT/IMPROVEMENT

The identification and estimation of air quality impacts from fugitive dust sources typically requires the use of air quality models. For purposes of discussion, these models may be segregated conveniently into two broad categories -- (a) source-oriented models, and (b) receptor-oriented models. The following discussion is intended to provide a general overview of both classes of models; for more detailed discussions, the user should consult recent reviews readily available in the scientific literature.[1-4] Prior to discussion, it should be recognized that both source and receptor models have a common physical basis. Both assume that mass transported from a source to a receptor was transported with conservation of mass by atmospheric dispersion of the source material.[5] It should also be recognized that the selection of an appropriate model(s) will depend upon the particular program/study objectives and resource constraints (i.e., data, manpower, computing facilities, etc.), as well as the user's knowledge of the model technology available.

A.1 SOURCE-ORIENTED MODELS

The "traditional" regulatory approaches have dictated that source impacts be identified by dispersion (source) modeling. In this context, the Gaussian plume model is more widely used than any other model. Stripped to its essentials, the Gaussian model may be represented as follows:

$$X = \left(\frac{Q}{2\pi u \sigma_y \sigma_z}\right) \exp\left(\frac{-Y^2}{2\sigma_y^2}\right) \exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) - \left(\frac{(z+H)^2}{2\sigma_z^2}\right)$$

where the parameters are:

X (g/m^3) = concentration of pollutant in air

Q (g/s) = continuous point source strength

u (m/s) = wind speed at height H

σ_y (m) = lateral dispersion parameter

σ (m) = vertical dispersion parameter

Y (m) = lateral distance from plume centerline

z (m) = height above ground

H (m) = final plume rise of plume above ground

As the name implies, the model predicts concentrations under the assumption that the plume disperses in the horizontal and vertical according to a Gaussian distribution. Other major assumptions include: (a) constant and continuous emission rates, (b) no variations in meteorology (wind speed, wind direction, and atmospheric stability) between source and receptor, and (c) complete reflection of the plume from the ground surface.

The Gaussian plume concept is the basis for nearly all models in the U.S. EPA system of UNAMAP (User's Network for Applied Modeling of Air Pollution) models. The differences between models of the UNAMAP family are mostly due to variations in the treatment of (a) plume rise, (b) pollutant half-life, (c) diffusion limitations due to mixing heights, (d) source configurations, and (e) dispersion coefficients to characterize plume growth. Abstracts which summarize model capabilities of most of the current generation of UNAMAP models may be found elsewhere.[6] Reasonably complete technical descriptions for each model are available in the various User's Manuals.

For all but the crudest screening applications, the use of a dispersion model requires appropriate information on (a) source emission rates, and (b) study area meteorology. In the case of stationary sources, it is usually a fairly straightforward procedure to develop an adequate emissions inventory. For fugitive (particularly open source) emissions, the measures of source extent (e.g., unvegetated surface area exposed to the wind) are often more difficult to define. As noted earlier, the reliability of open source emissions estimates are greatly increased if site-specific information is collected.

In similar fashion, to make the best use of Gaussian modeling, site-specific meterological measurements need to be made that relate closely to pollutant dispersion.[7] These include, for example, (a) continuous measurements of wind speed (u) and direction (Θ) at two heights; (b) ambient temperature difference (ΔT) between 2 and 10 m, and (c) heights of the convectively mixed layer (h_c) and the mechanically mixed layer (hm). Very few programs are designed to acquire such detailed information.

Many routine modeling applications rely on data from nearby locations such as airports, National Weather Service stations, and military installations to represent the atmospheric conditions for the area of interest. These observations are intended primarily for aviation needs, and are not particularly well suited to dispersion problems. The primary source for surface and upper air meterological data is the National Climatic Data Center (NCDC, Asheville, NC). For many long-term or climatological applications, the meteorological conditions of a site are represented by a stability array or "STAR" tabulation. The STAR tabulation summarizes meteorological conditions in terms of joint frequency distributions of wind speed, atmospheric stability class, and wind direction. This information has been developed for many locations in the United States and is also available from NCDC.

The principal advantage of source-oriented (dispersion) models lies in the fact that they can be used to directly predict the impact of either existing or proposed sources.[5] Another advantage of this class of models is that they do not require ambient air quality data, though, if available, air quality data may be used to assign "background" pollutant levels. Additional advantages are that the models are widely available, and have been evaluated using many different data sets.[4]

The primary limitations of dispersion models relate not only to deficiencies in the quality of the input data for a particular application, but also to the ability of the Gaussian model to reproduce the important physical/chemical processes affecting transport of pollutants in the atmosphere.

The Gaussian model will perform best under the conditions used to form the basis for the current models. These conditions include:

Source:	Low-level, continuous, nonbuoyant emissions, in simple terrain.
Meteorology:	Near neutral stability, steady, and relatively homogeneous wind field.
Estimate:	Local, short-term, concentrations of inert pollutants.

Under those relatively simple conditions, "factor of two" agreement between predicted and observed concentrations is probably realistic.[8]

Addition of complicating features to the simple dispersion case will substantially increase the uncertainties associated with model estimates. Complicating features include:

1. Aerodynamic wake flows of all kinds.
2. Buoyant fluid flows and accidental releases of heavy toxic gases.
3. Flows over surfaces markedly different from those represented in the basic experiments, e.g., forests, cities, water, complex terrain.
4. Dispersion in extremely stable and unstable conditions.
5. Dispersion at great downwind distances (> 10 to 20 km).

It is widely recognized that significant improvements in dispersion modeling will require more direct observational knowledge under these conditions. Model users should be aware that the capabilities of the current UNAMAP series to represent these features are based on a few special case studies.[9]

A.2 RECEPTOR-ORIENTED MODELS

Unlike dispersion models, receptor-oriented techniques begin with particulate measurements at a receptor(s) and then "back calculate" to estimate source contributions. Receptor models also differ from source models in that they do not require a formal description of the transport meterology of the area. Receptor models may be conveniently grouped into two basic categories, microscopic, and chemical methods; these may be further subdivided as shown in Table A-1. Each of these techniques has particular advantages and disadvantages for problems of source apportionment, however, none of the receptor models are predictive tools and as such have minimal applicability in directly estimating the effectiveness of future control strategies.[5]

TABLE A-1. TYPES OF RECEPTOR MODELS

1. Microscopic Methods
    - Optical
    - Scanning electron microscopy (SEM)
    - Automated SEM
2. Chemical Methods
    - Enrichment factors
    - Time series analysis
    - Spatial series analysis
    - Chemical mass balance (CMB)
    - Advanced multivariate methods

A.2.1 Microscopic Methods

Microscopic methods are the older of the two classes of receptor models. Optical methods are limited to particles greater than about 2 μm. One advantage of optical methods is that an experienced analyst can use features such as color, surface texture, and optical properties to aid in particle identification.[10] A corresponding disadvantage of the method is that the reliability of the results is then highly dependent upon individual operator skill. A more sophisticated method, scanning electron microscopy (SEM), can be applied to identify submicron (< 1 μm) particles. This technique may also include a determination of major chemical elements to aid in qualitative particle type assignment. Automated SEM is the newest of the microscopic methods; it uses all of the same qualitative particle type identification features as SEM but has the capability of analyzing more particles because of its automation.[2]

Another advantage of microscopic methods is that they do not explicitly require a knowledge of the chemical composition of source emissions. By virtue of its wide use, an extensive library of "microscopic fingerprints," including morphological, color, and elemental features, has already been developed.[5] In general, these methods have a high source resolving capability for sources with characteristic morphological features such as wood fiber, tire rubber, pollen, etc.

To be quantitative, microscopic methods require estimates of the number of particles, their density and volume. It is also critical that a sufficient number of particles be analyzed to be representative of the total sample. A major disadvantage of microscopic methods lies in the large uncertainties associated with determination of particle density and volume.[5] Other limitations include time and cost per analysis, and lack of reliability in identifying amorphous organic species which in many applications may account for a large fraction of the aerosol.

A.2.2 Chemical Methods

Unlike microscopic methods, all chemical methods require knowledge of the chemical composition of both the ambient aerosol and possible sources.[2] Three of the techniques, enrichment factors, time series analysis, and spatial series analysis, may be classified as relatively "simple" to apply.[10] With the enrichment factor model, data on the composition of the ambient air (i.e., at the receptor) is used with a normalizing or reference element (usually a crustal element such as Fe, Al, or Si) to estimate the degree to which a specific element has been "enriched" by an anthropogenic source. This method relies heavily on the assumed background composition and is inapplicable to complex source mixtures in which multiple sources are contributing the same element.[2] The method would appear to have little applicability for problems concerning open dust source emissions.

Time series techniques are based on the assumption that chemical species originating from the same source will exhibit the same temporal dependence when measured at a receptor. Thus, if a set of elements at a receptor are temporally correlated, they are presumed to have a similar source. From the viewpoint of source apportionment, time series correlation must be considered a qualitative technique. Nevertheless, long-term studies covering several years can be valuable in assessing the impact of seasonally dependent sources or in the implementation of control measures.[2]

Spatial models focus on comparison of air quality data collected for the same time period from a number of different receptors. Qualitative comparisons then are obtained by further comparison with the location of known emission sources. Various forms of the spatial model include isopleths, spatial correlations, and pollutant wind roses. In many source apportionment applications, particularly those on the scale of a single industrial facility, spatial variations may be of less importance than temporal variations.

The remaining two receptor models, chemical mass balance (CMB) and multivariable methods, generally are considered to be more resource intensive than the other chemical methods. Under the assumption of conservation of mass (for each chemical component), the CMB model may be expressed as:

$$C_i = \sum_{j=1}^{p} F_{ij} \cdot S_j$$

where C_i is the concentration of the chemical component i measured at the receptor, F_{ij} is the fraction of chemical i emitted by source j as determined at the source, and S_j is the source contribution (i.e., the ratio of the mass contributed by source j to the total mass at the receptor.[5] It is possible to calculate the source type contribution (S_j) by least squares methods[1] with the following additional assumptions:

- The number of sources, p, is less than or equal to the number of components; and
- The source compositions (F_{ij}) are linearly independent of each other.

In practice, these assumptions are not met, and considerable uncertainties are attached to the results.[1]

The CMB method is based on analysis of a single filter. The most significant limitation to source resolution with the CMB method is the uncertainty in the F_{ij} values.[2] These values can vary with time, location, raw material, fuel type, etc. An additional limitation lies in the fact that since many fugitive sources have similar source compositions, they cannot be resolved as distinct sources based on the ambient concentration data.

The major difference between the CMB and multivariate methods is that CMB is based on the composition data of a single sample, and the multivariate methods analyze the variability of elements measured in a large number of samples. All the multivariate methods are based on a correlation matrix which shows the association between elements/samples. In one method, factor analysis, the correlation matrix is "collapsed" to yield the minimum number of factors required to reproduce the ambient data matrix, their relative chemical composition, and their contribution to the mass variability.[5] A major limitation of the factor analysis technique lies in the abstract nature of the resulting composite variables (factors) and the difficulty of assigning source names to the variables. Various modifications to this technique have been explored in efforts to improve the method's ability to associate these composite variables with known sources.[11,12]

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APPENDIX B
GLOSSARY

Air Quality Models - An equation, or series of equations which predict a source impact on air quality.

Annualized Cost - The control technique cost ($/yr) calculated as annual cost over the useful life of the equipment (or application). The annualized cost is a sum of the annualized purchase and installation cost (i.e. capital costs) and the annual maintenance and operating costs.

Application Frequency - Number of applications of a control measure to a specific source per unit time; equivalently, the inverse of time between two applications.

Application Intensity - Volume of water or chemical solution applied per unit area of the treated surface.

Canopy Hood - A receiving hood located above the source of emissions intended to capture the emissions as the emissions are directed upward due to thermal gradients (e.g. a canopy hood for capturing furnace charging emissions).

Capital Recovery Factor - The factor which is used to annualize capital investment to obtain the annualized capital cost. The capital recovery factor is a function of annual interest rate and the total number of payment years.

Capture Device - A system for capturing emissions generated by a process or materials handling operation (e.g. receiving hood, side draft hood).

Capture Efficiency - The efficiency at which an air pollution control system captures fugitive emissions (e.g. hood). That is, the mass emissions captured divided by the total uncontrolled emissions generated by the source times a factor of 100.

Close Capture Hood - A receiving hood located in close proximity to the source of emissions.

Collection Device - A gas cleaning device for removing air pollutants from the air stream passing through it (e.g. baghouse, scrubber, electrostatic precipitation).

Collection Efficiency - The efficiency of an air pollution collection device (e.g. baghouse). That is, the mass emissions collected divided by the mass emissions entering the device times a factor of 100.

Collection Hood - A hood designed to capture particulate matter emissions by inducing a draft on the emission plume, thereby pulling the emissions into the hood.

Control Efficiency - Percent decrease in controlled emissions from the uncontrolled state.

Cost-Effectiveness - The cost of control per unit mass of reduced particulate emissions.

Dilution Ratio - Ratio of the number of parts of chemical to the number of parts of solution, expressed in percent (e.g., one part of chemical to four parts of water corresponds to a 20% solution).

Dry Sieving - The sieving of oven-dried aggregate by passing it through a series of screens of descending opening size.

Duration of Storage - The average time that a unit of aggregate material remains in open storage, or the average pile turnover time.

Dust Suppressant - Water or chemical solution which, when applied to an aggregate material, binds suspendable particulate to larger particles.

Emission Factor - An estimate of the mass of uncontrolled emissions released to the atmosphere per unit of source extent (e.g. kg/ton product).

Emissions Inventory - A listing and classification of all sources of emissions, and the quantity of emissions generated for a specific geographic area or facility.

Emission Rate - Mass of emissions generated per unit time (e.g. kilogram per hour).

Enclosures - A common preventive measure for the control of fugitive particulate matter emissions which involves either totally or partially enclosing the source to inhibit or contain emissions.

Erosion Potential - Total quantity of erodible particles, in any size range, present on the surface (per unit area) prior to the onset of erosion.

Exposed Area - Outdoor ground area subject to the action of wind and protected by little or no vegetation.

Exposure Profiling Method - A method for quantifying fugitive emissions which involves the isokinetic measurement of airborne pollutant immediately downwind of the source by means of simultaneous multipoint sampling over the effective plume cross section.

Fine Particulate (FP) - Particulate matter less than or equal to 2.5 μm in aerodynamic diameter.

Fugitive Dust - Solid particles generated by the action of wind or machinery which are not emitted from a stack, duct or flue.

Fugitive Emissions - Emissions not originating from a stack, duct, or flue.

HVLV Local Exhaust - A high velocity, low volume induced draft hood located right at the source to capture the emissions.

Inhalable Particulate (IP) - Particulate matter less than or equal to 15 µm aerodynamic diameter.

Load-in - The addition of material to a storage pile.

Load-out - The removal of material from a storage pile.

Materials Handling - The receiving and transport of raw, intermediate and waste materials, including barge/railcar unloading, conveyor transport and associated conveyor transfer and screening stations.

Moisture Content - The mass portion of an aggregate sample consisting of unbound moisture as determined from weight loss in oven drying.

Open Dust Sources - Sources of fugitive emissions that entail generation of particulate matter by the forces of wind or machinery acting on exposed (i.e. open) materials where no physical or chemical change occurs to the particle-generating material.

Partially Enclosed Materials Handling Operations - Partially enclosed sources which generate fugitive emission during the storage or transfer of materials to or from a process operation.

Particle Diameter, Aerodynamic - The diameter of a hypothetical sphere of unit density (1 g/cm^3) having the same terminal settling velocity as the particle in question, regardless of its geometric size, shape and true density.

Plume Aftertreatment - The application of a fine water spray or fog to the suspended particulate plume near the source to capture and agglomerate the particles by inertial impaction so that gravitational settling can occur.

PM-10 - Particulate matter less than or equal to 10 μm in aerodynamic diameter.

Preventive Measures - Techniques for controlling fugitive particulate emissions which prevent the creation and/or release of particulate matter (e.g. wet suppression, stabilization of unpaved surfaces, cleaning of paved surfaces).

Process Sources - Sources of fugitive emissions associated with industrial operations that alter the chemical or physical characteristics of a feed material.

Quasi-Stack Method - A method for quantifying fugitive emissions which involves capturing the entire emissions stream with enclosures or hoods and then applying conventional source testing techniques to the confined flow.

Receiving Hood - A hood designed to capture particulate emissions which are directed at the hood from the source by thermal or mechanical forces.

Receptor-Oriented Air Quality Model (Receptor Model) - An air quality model which uses chemical analysis at receptors (i.e. ambient monitors), to statistically infer the separate contribution from each of the sources of the emissions.

Respirable Particulate (RP) - Particulate matter less than or equal to about 3.5 μm aerodynamic diameter, as measured with a 10-mm Dorr-Oliver cyclone precollector.

Road, Paved - A roadway constructed of rigid surface materials, such as asphalt, cement, concrete, and brick.

Road, Unpaved - A roadway constructed of nonrigid surface materials such as dirt, gravel (crushed stone or slag), and oil and chip surfaces.

Road Surface Dust Loading - The mass of loose surface dust on a paved roadway, per length of roadway, as determined by dry vacuuming.

Road Surface Material - Loose material present on the surface of an unpaved road.

Roof Monitor Method - A method for quantifying fugitive emissions which involves measurement of mass concentrations and air flows at multiple points in well defined building openings such as roof monitors, ceiling vent, or windows.

Side Draft Hood - A type of capture device which operates by inducing a sideways draft thereby pulling emissions into the hood.

Silt Content - The mass portion of an aggregate sample smaller than 75 micrometers in diameter as determined by dry sieving.

Source Extent - The measure of the level of source activity (e.g. tons product per year, tons feed per day, BTU per hour).

Source-Oriented Air Quality Models (Dispersion Models) - An air quality model which predicts a source's impact on air quality by using a series of predictive equations to model the dispersion of the plume from the source.

Spray System - A device for applying a liquid dust suppressant in the form of droplets to an aggregate material for the purposes of controlling the generation of dust.

Stabilization - The use of chemical dust suppressants for the control of fugitive particulate emissions from open dust sources (e.g. unpaved roads) or material storage piles.

Storage Pile Activities - Processes associated with aggregate storage piles, specifically, load-in, vehicular traffic around storage piles, wind erosion from storage piles, and load-out.

Surface Cleaning - A method for reducing the surface loading of particulates on paved surfaces to reduce particulate emissions (e.g. street cleaning).

Total Particulate (TP) - Particulate matter of all sizes as collected by isokinetic sampling.

Total Suspended Particulate (TSP) - Particulate matter measured by a high volume sampler with an inlet 50% cutoff 30-50 μm in aerodynamic diameter.

Upwind-Downwind Method - A method of quantifying fugitive emissions which involves the measurement of air quality upwind and downwind of the source under known meteorological conditions, followed by "back-calculation" of source emission rates using atmospheric dispersion equations.

Vehicle, Heavy-Duty - A motor vehicle with a gross vehicle travelling weight exceeding 30 tons.

Vehicle, Light-Duty - A motor vehicle with a gross vehicle travelling weight of less than or equal to 3 tons.

Vehicles, Medium-Duty - A motor vehicle with a gross vehicle travelling weight of greater than 3 tons, but less than 30 tons.

Wet Suppression - The application of water or a water solution of a chemical agent to the surface of the material producing emissions to inhibit the generation of particulate matter emissions.

Wind Fences/Barriers - Man-made structures or vegetative barriers used to control emissions from open sources (e.g. material storage piles) by providing an area of reduced wind velocity at the source.

Wind Tunnel Method - A method for measuring wind erosion emissions which involves using a portable pull-through wind tunnel with an open-floored test section. The portable wind tunnel is placed directly over the surface to be tested, air is drawn through the tunnel, and emissions are measured by an isokinetic probe fitted at the downstream end of the tunnel.